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PHASE I REPORT

STUDY OF

INNOVATIVE TECHNIQUES TO REDUCE SUBSURFACE DRAINAGE FLOWS

prepared
under contract for the

Federal-State
San Joaquin Valley
Drainage Program

NOVEMBER 1987

This report presents the results of a study conducted for the Federal-State Interagency San Joaquin Valley Drainage Program. The purpose of the report is to provide the Drainage Program agencies with information for consideration in developing alternatives for agricultural drainage water management. Publication of any findings or recommendations in this report should not be construed as representing the concurrence of the Program agencies. Also, mention of trade names or commercial products does not constitute agency endorsement or recommendation.

The San Joaquin Valley Drainage Program was established in mid-1984 as a cooperative effort of the U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Geological Survey, California Department of Fish and Game, and California Department of Water Resources. The purposes of the Program are to investigate the problems associated with the drainage of irrigated agricultural lands in the San Joaquin Valley and to formulate, evaluate, and recommend alternatives for the immediate and long-term management of those problems. Consistent with these purposes, Program objectives address the following key areas: (1) Public health, (2) surface- and ground-water resources, (3) agricultural productivity, and (4) fish and wildlife resources.

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PHASE I REPORT

Study of

INNOVATIVE TECHNIQUES TO REDUCE SUBSURFACE DRAINAGE FLOWS

Prepared for the

San Joaquin Valley Drainage Program
2800 Cottage Way, Room W-2143
Sacramento, CA 95825-1898

Under

U.S. Bureau of Reclamation
Contract No. 7-CS-20-05160

By

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November 1987

PHASE I REPORT TO THE SAN JOAQUIN VALLEY DRAINAGE PROGRAM

STUDY OF INNOVATIVE TECHNIQUES TO REDUCE SUBSURFACE DRAINAGE FLOWS

EXECUTIVE SUMMARY

This study develops irrigation management and controlled drainage techniques which can be accomplished on tile drained fields to reduce the volume of subsurface drainage flow without reducing crop yields. The study focuses on the areas with tile drains which drain through the South Grasslands to the San Joaquin River. The irrigation management techniques include irrigation evaluations and irrigation scheduling. The irrigation systems in the study will be the dominant existing irrigation method of the area, surface irrigation. The controlled drainage techniques will include in-line weirs or flow control valves located in the tile drains. These techniques will encourage more crop use of water from the shallow water table while still providing drainage for salinity control and protection of the crop root zone from saturated conditions.

This report presents background information specific to the area studied. Included is the hydrogeology, cropping, irrigation water quality, soils, subsurface drainage systems, and the subsurface drainage water quality and quantities within the area. All of these factors enter into the design and implementation of a drainage flow reduction program.

Basic information on the irrigation and drainage management theory and practice which form the components of the drainage reduction plan are also presented. Components include irrigation scheduling, irrigation evaluation, sub-surface drainage, and salinity control. A conclusion of this report is that existing methods for managing irrigation and drainage of lands with shallow water tables are inadequate because of crop water use from the shallow water table. There is a need for a tool to tie together these components in order to make both irrigation and drainage manageable.

A procedure is developed to determine the limiting net deep percolation which can be achieved in a given field without promoting salinization of significant portions of a field. The limiting net deep percolation depends on the leaching requirement (which is set by the crop and irrigation water quality) and the annual distribution uniformity of applied water. In the study area, leaching requirements are very small, so the annual distribution uniformity becomes the major factor determining the limit to which sub-surface drainage flows may be reduced.

A computer water balance model was selected (DRAINMOD, developed by Dr. R.W. Skaggs of North Carolina State University) to be used for designing and managing the drainage flow reduction program.

A weather based irrigation scheduling computer program (SWAP/ET, a J.M. Lord, Inc. in-house program) was selected to feed evapotranspiration data into DRAINMOD. While recognized as needing more testing and possibly modification, these programs are proposed as tools to tie the components of irrigation management and controlled drainage into one manageable package. They can be used for designing an irrigation and drainage management program for existing as well as new tile drained fields.

DRAINMOD has been developed and tested extensively in humid regions of the U.S., and has been subjected to limited testing in arid regions. In this phase it was used to run several trial scenarios with varying levels of irrigation management and varying uncontrolled and controlled drainage configurations. Basic inputs for DRAINMOD and SWAP/ET were developed from crop, soil, irrigation, and weather data from the study area. The trial runs showed the potential of irrigation management and controlled drainage to reduce both the annual sub-surface drainage volumes and the peak flows.

The affects of flow reduction on water quality are discussed, though this initial study cannot answer many of the questions about load-flow relationships.

The flow reduction program's affect on discharges to various disposal facilities are also discussed. The flow reduction program should provide a positive benefit to all of the disposal facilities currently being considered. The flow control scenario showed the largest reduction in peak flows while the weir control scenario showed the largest reduction in annual flows.

This study brings out that it is important to understand that there are components of subsurface drainage flows which cannot be reduced by the proposed methods. These components include seepage from canals and ditches and subsurface inflow from areas outside of the field boundary. Another component which can not be reduced are flows generated from fields which need reclamation water applications to bring soil salinity and boron levels below levels where the crop is damaged. Other practical limitations to the drainage flow reduction fall into three categories: drainage system configuration problems, farmer implementation, and institutional constraints. Most of these can limit the use of controlled drainage techniques more than the irrigation management part of the program.

It is believed that subsurface drainage flows can be reduced in many fields with the proposed techniques. However, insufficient data on the existing net deep percolation amounts occurring in the study area, and the distribution uniformities which can be achieved, make it impossible to predict a percentage reduction that the proposed drainage flow reduction program could make in the study area.

The design and management of the proposed drainage reduction program must be done on a field by field basis with assistance from qualified irrigation and drainage experts. Estimated costs of implementing a drainage reduction program are $25 to $50 per acre for the first year's design and management, $12 to $90 per acre for installation of drainage control hardware, and $16 to $30 per acre in succeeding years for management consulting.

The funding and the motivation for implementing such a drainage flow reduction program will come when it is cheaper for the grower to reduce the subsurface drainage volume than to treat and/or dispose of a larger amount of water. In many cases, the other benefits of subsurface drainage flow reduction such as increased yield, reduced water, fertilizer, and labor costs offset some if not all of the costs involved.

The next phase of this study will be to conduct a two year field trial of customized drainage flow reduction programs in three fields within the study area.

PHASE I REPORT TO THE SAN JOAQUIN VALLEY DRAINAGE PROGRAM

STUDY OF INNOVATIVE TECHNIQUES TO REDUCE SUBSURFACE DRAINAGE FLOWS

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PHASE I REPORT TO THE SAN JOAQUIN VALLEY INTER-AGENCY DRAINAGE PROGRAM

STUDY OF INNOVATIVE TECHNIQUES TO REDUCE SUBSURFACE DRAINAGE FLOWS

I. INTRODUCTION

A. STUDY OBJECTIVE

The goal of this study is to develop irrigation management and water table control techniques which can be done on tile drained fields in order to reduce the volume of subsurface drainage flow without reducing crop yields. The study also seeks to assess the amount of drainage flow reduction which can practically be achieved by these same methods. The study area focuses on those subsurface drainage systems which drain through the South Grasslands and to the San Joaquin River.

The irrigation management techniques are to be done using the predominant existing irrigation method, surface irrigation. The water table control techniques will consist of installing flow or water level control gates in the existing tile drain systems and managing the buildup in a controlled way to increase the availability of the water table for use by the crop for its water needs.

B. WORK DONE IN PHASE I

Phase I of the study covers work done in Fiscal Year 1987 (ending on September 30, 1987). The first work item was to review existing literature for information pertaining to crop water use from a shallow water table, salt balance, leaching requirement, crop salt tolerance, and drainage system design. Background information was also gathered on the existing drainage systems, soil types, crops grown, irrigation water quality, drainage water quantity and quality, and geohydrology of the study area. A drainage flow reduction scheme was then proposed using the tools available from current research. A computer water balance model was selected (DRAINMOD, developed by Dr. R.W. Skaggs of North Carolina State University) for designing and managing the drainage flow reduction program. The SWAP/ET model of JMLord, Inc.'s was selected as a working partner with DRAINMOD. Simulations were used to evaluate several different hardware and management scenarios to accomplish drainage reduction. Based upon the studies done in Phase I, an evaluation of the potential for reducing subsurface drainage flows was made. Phase I included initial contact with growers in the study area who might allow use of their fields for field trials of the drainage flow

reduction program.

C. WORK TO BE DONE IN THE FUTURE

Three trial fields with existing tile drain systems will be selected in the drainage study area for implementing a drainage flow reduction program. Basic information will be gathered for modeling the fields with DRAINMOD-SWAP/ET, including the drainage system layout, soil profiles, hydraulic conductivity, past irrigation schedules, soil salinity, etc. A drainage reduction program will be designed for each of the three trial fields. Where possible, each of the trial fields will have an adjacent field or a portion of the same field which will not be changed for comparison. Then, for two years the drainage reduction program will be implemented along with an intense monitoring program. The monitoring program will include measurements of rain and irrigation applications, subsurface and surface runoff flows, water table levels, irrigation and drainage water quality, and soil salinity. Meanwhile, work will continue on perfecting the techniques used to reduce the subsurface drainage flows. At the end of two years, a final report will summarize the work done and project the potential for the various methods of drainage reduction.

II. BACKGROUND INFORMATION

A. DRAINAGE STUDY AREA

The study area boundary is essentially the same as was used in the recent California Water Resources Control Board Report, Regulation of Agricultural Drainage to the San Joaquin River. It is the area South of the Central California Irrigation District's Main Canal which has surface and subsurface drainage systems that drain through the South Grasslands to the San Joaquin River (Figure 1). The study area includes two portions of Central California Irrigation District (C.C.I.D.), and all of Firebaugh Canal Company, Broadview Water District, Widren Water District, Panoche Drainage District, Pacheco Water District, and Charleston Drainage District. The study area also includes some lands that are between but not within any of these districts.

Each of the water agencies mentioned has its own history of development. C.C.I.D. and Firebaugh Canal Company are holders of riparian rights to water from the San Joaquin River, being descendants of Miller and Lux. Many of the lands within C.C.I.D. have been irrigated with San Joaquin River water since the 1880's. Firebaugh Canal Company developed later, using pumped water from the San Joaquin River. In 1951, C.C.I.D. and Firebaugh Canal Company exchanged their river water supply for water brought south from the Sacramento-San Joaquin Delta in the Delta Mendota Canal (Federal Water Project). The Delta Mendota Canal (D.M.C.) also brought a reliable surface water supply to Broadview Water District, Panoche Water District, Pacheco Water District, Oro Loma Water District, Eagle Field Water District, and Mercy Springs Water District. These areas had developed some irrigated agriculture using deep well water and pumped San Joaquin River Water prior to the D.M.C. and developed fully after the D.M.C. was built.

When the California Aqueduct was built in 1967 as part of the State Water Project, the Panoche Water District began to receive some of its water from the aqueduct. Currently, most of the water used in the study area comes from the Delta Mendota Canal. During abnormally wet years, C.C.I.D. and Firebaugh Canal Company will still use the San Joaquin River water which is released as excess from Friant Dam before it uses the D.M.C. water.

Surface drainage ditches were developed along with the irrigation systems. Open drains were built to drain surface waters through the South Grasslands to the San Joaquin River in C.C.I.D., Firebaugh Canal Company, Panoche Drainage District (includes Panoche, Oro Loma and Eagle Field Water Districts), and Pacheco Water District. Some of the drainage water was reused in these districts. Broadview Water District had no outlet to the Grasslands and recycled all of its drainage waters.

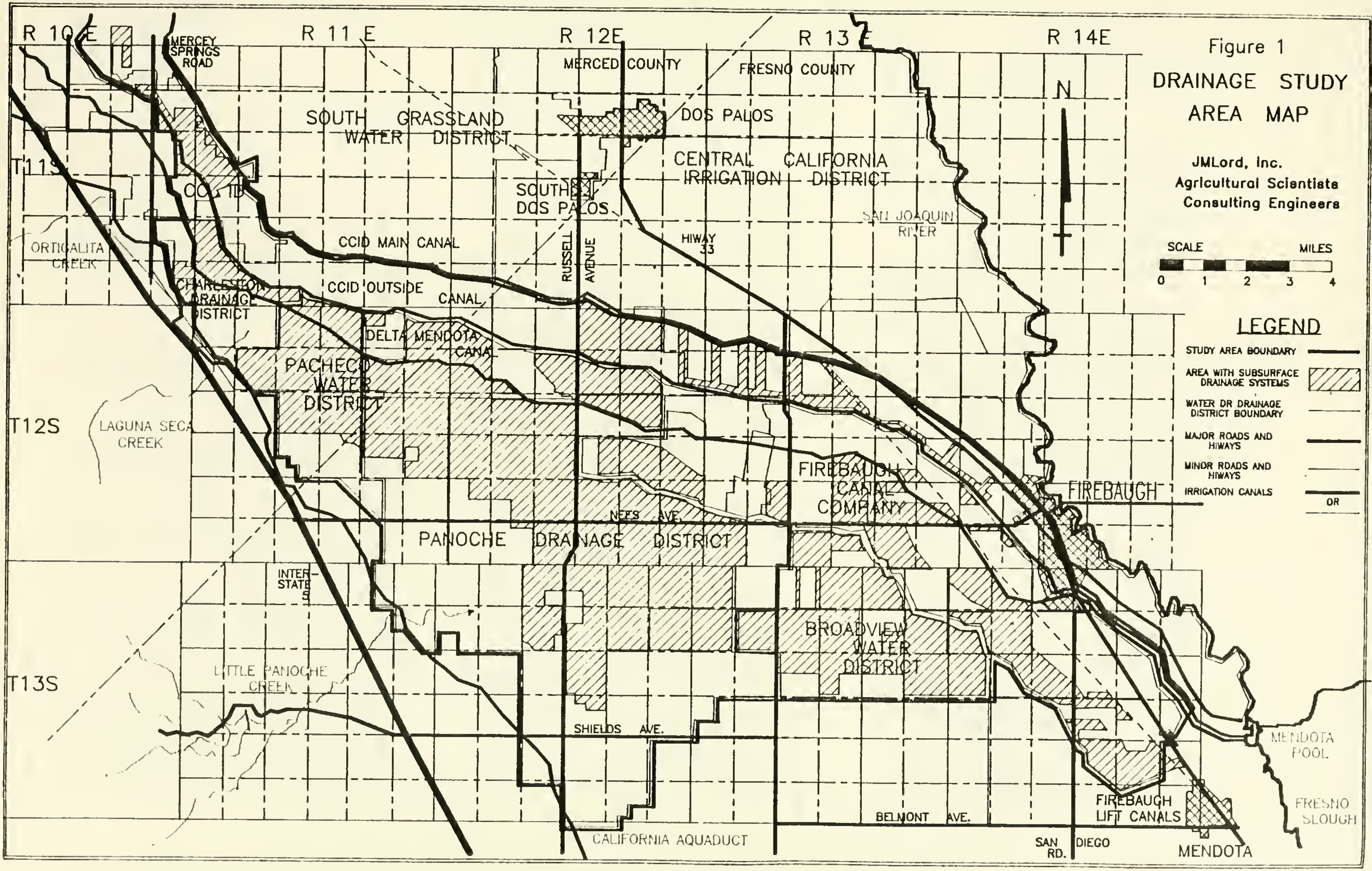


Figure 1 DRAINAGE STUDY AREA MAP

JMLord, Inc.
Agricultural Scientists
Consulting Engineers

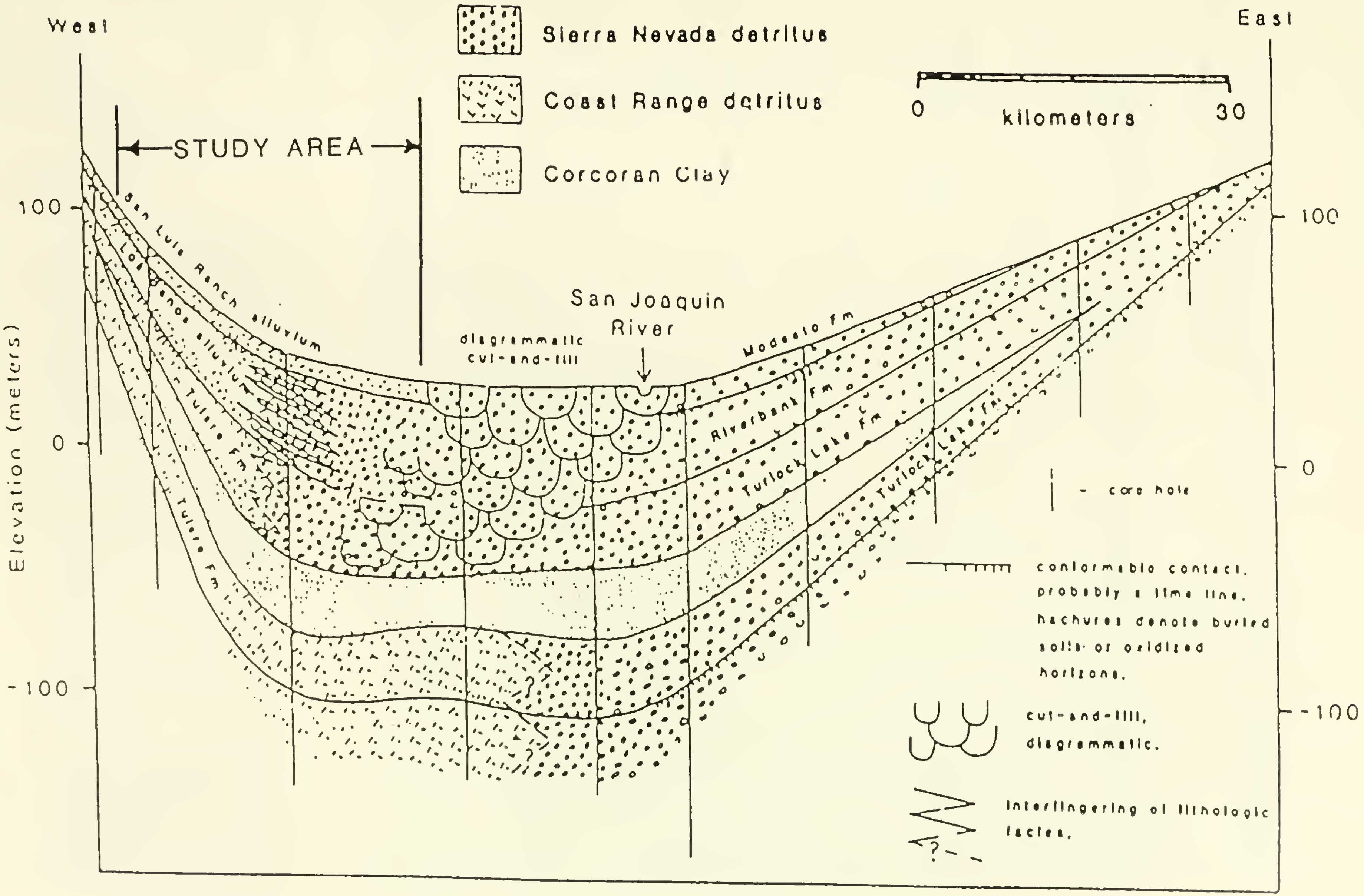
The installation of subsurface drainage systems began with the excavation of deep drains in areas which developed a high water table. Many of these drains function as both surface and subsurface drains. In 1951, tile drainage systems began to be installed. This continued until 1983 when the problem of selenium in the drainage waters caused the districts to put a moratorium on the installation of new systems. The tile drainage water was either gravity drained or lifted with sump pumps into the surface drains. Some of the blended water was reused and the rest drained through the South Grasslands to the San Joaquin River. In 1982, a buildup of soil salinity within Broadview Water District caused it to open up an outlet for subsurface and surface drainage waters to the South Grasslands. Figure 1 shows the areas with subsurface drains in the study area.

B. HYDROGEOLOGY

Most of the study area lies on the Little Panoche, Panoche Creek, and a few smaller alluvial fans which are nested along the east slope of the foothills of the Diablo Range (Geological Survey Professional Paper 352-E). The fans have been built primarily of sediment shed from the Diablo Range. The alluvial sediments consist of unconsolidated, poorly sorted to well-sorted gravel, sand, silt, and clay (Lettis, 1982). A simplified geologic cross section through the study area from the report by Lettis is shown in Figure 2. On the northern and eastern boundary of the study area, there is a transition from the alluvial fan sediments of the Diablo Range to sediments of the floodplain of the San Joaquin River derived primarily from the Sierra Nevada Mountains. The flood plain sediments have well-sorted, fine and medium grained, quartzose, cross bedded sands which locally interfinger with or underlie the fine grained Coast Range alluvial fan deposits.

The Corcoran Clay layer underlies the study area at 500 to 800 feet below the surface. This layer's low permeability causes it to act as an aquiclude, or water barrier, to the groundwater transfer between the aquifer above and below. Water which percolates below the crop root zones, and/or below the subsurface drains, from rain, irrigation, or ditch seepage tends to descend downward and laterally (when it encounters low permeable layers) until it reaches the water table level in the aquifer above the Corcoran Clay. In some areas, the layering of the alluvial sediments has created a perched groundwater table above the aquifer which sits on the Corcoran Clay. In the past, scientists have blamed nearly all of the shallow groundwater problems of the West side of the San Joaquin Valley on these perched layers. More recently, some scientists are beginning to believe that much of the shallow groundwater observed is actually the top of the water surface of the aquifer above the Corcoran Clay (Schmidt,

Figure 2. Geologic Cross Section



Source: Lettis (1982)

1986). In other words, the "bath tub" created by the Corcoran Clay has filled up to where the water has reached to the ground surface near the valley trough.

Groundwater movement below the study area is not fully understood. Deep percolating water from areas higher in elevation may perch on clay layers and flow laterally downslope. These waters may percolate to the groundwater above the Corcoran Clay. Once joined with the deeper groundwater, this water will add to the build-up of the groundwater. When a lateral gradient develops, flow will be laterally to areas with lower water table elevations. The velocity of lateral groundwater flow is relatively slow, except in gravel, and is measured in terms of feet per year. As the ground water builds up in higher elevation areas on the alluvial fan, the lower areas can become subject to upward, or artesian, pressure. This tends to drive water up into the subsurface drainage systems in the lower lying areas. In locations where there are old streambeds or underlying sand layers, the contribution to subsurface drainage system flow from upslope (including neighboring undrained fields) can become a very significant portion of the total flow. One area at the Northwest tip of the study area within C.C.I.D. has drainage systems where as much as 10 acre feet per drained acre per year is generated while deep percolation from irrigation of those fields accounts for only 1 acre foot. (Day, 1986). These systems are known to have been installed in areas where there are gravelly remnants from Los Banos Creek. On the other hand, a study of the flow hydro-graphs from tile drainage systems in Broadview Water District found that contributions from upslope appeared to be minor (Day and Nelson, 1987). Studies by the U.S.G.S. and Schmidt, unpublished data, have measured pressure and velocity gradients which show flows coming from upslope on the alluvial fan into the lower lying areas.

The hydrogeologic effects on subsurface drainage have been neglected in many drainage studies and designs but need to be included when drainage reduction is considered.

C. CROPS GROWN IN THE STUDY AREA

The State Water Resources Control Board's 1987 Technical Committee Report on Regulation of Agricultural Drainage to the San Joaquin River presented a table (reproduced in this report as Table 1) which shows the percent of the drainage study area farmed in various crops from the years 1978 to 1984. Cotton is by far the largest with grain next. Alfalfa, sugar beets, tomatoes, melons and safflower are also significant percentages of the acreage. The distribution of crops grown on the fields with subsurface drains may be somewhat different since the table was developed for the whole study area, which includes fields without subsurface drains.

TABLE 1

Percentages of Major Crops in the Drainage Area,
1978 - 1984

Crop	Avg. % of Area
Cotton*	48.0
Grains*	13.2
Alfalfa	3.1
Sugar Beets	3.2
Tomatoes	8.6
Melons	3.6
Safflower	1.6
Other Vegetables	4.7

* 1983 excluded

Source: SWRCB (1987)

D. IRRIGATION WATER QUALITY

The irrigation water quality used within the drainage study area varies from year to year, month to month, and with location. Table 2 shows a summary of irrigation water analysis performed by JMLord, Inc.'s lab for four sites within the drainage study area since 1985.

Site PE-1 is representative of water delivered to the districts which use D.M.C. water. Note that no water was being delivered during the one analysis done in January 1985. Site PE-2 is representative of water delivered from the California Aqueduct to Panoche Water District. Site BV-2 is representative of the water delivered to Broadview Water District. This water is pumped from the Delta Mendota Canal with occasionally some tailwater and subsurface drainage water blended in. Site GL-33 is representative of water delivered to C.C.I.D. and Firebaugh Canal Company. The low EC values from February through May 1986 came when San Joaquin River water was being used rather than D.M.C. water.

An average Electrical Conductivity of 0.5 mmho/cm (DS/M) can used for the leaching requirement calculations for most locations in the study area which do not reuse tile drain water. (The leaching requirement is discussed in section III D of this report.)

Table 2. Summary of Irrigation Water Analysis

I.D.	Sample Location	Date Sampled	pH	Ec mmho	Ca+Mg meq/l	Na meq/l	HCO3 meq/l	SAR	SAR Adj	B ppm	NO3-N ppm	Cl meq/l
PE-1	D.M.C. @ Panoche Pump Sta.#1	01/14/85	7.9	2.40	15.0	17.3	6.0	6.3	23.6	4.50	60.2	12.4
PE-1	D.M.C. @ Panoche Pump Sta.#1	02/13/85	7.7	0.54	4.2	3.4	1.3	2.3	6.2	0.31	8.4	2.6
PE-1	D.M.C. @ Panoche Pump Sta.#1	03/15/85	7.8	0.31	4.2	1.4	0.5	1.0	2.2	0.64	8.2	1.1
PE-1	D.M.C. @ Panoche Pump Sta.#1	05/15/85	8.0	0.70	4.4	3.7	0.5	2.5	5.7	0.52	7.2	3.1
PE-1	D.M.C. @ Panoche Pump Sta.#1	07/17/85	7.6	0.57	4.0	3.0	0.5	2.1	4.6	0.31	7.4	3.1
PE-1	D.M.C. @ Panoche Pump Sta.#1	08/15/85	7.6	0.53	3.4	3.5	0.8	2.7	6.2	0.63	6.2	1.9
PE-1	D.M.C. @ Panoche Pump Sta.#1	09/17/85	7.9	0.59	3.4	2.7	0.8	2.0	4.8	0.28	5.0	2.7
PE-1	D.M.C. @ Panoche Pump Sta.#1	04/16/86	7.6	0.39	3.6	0.1	0.8	0.1	0.2	0.22	4.8	1.1
PE-2	Cal. Aqueduct @ Panoche T.O.#2	01/14/85	7.5	0.35	3.2	1.7	1.7	1.4	3.7	0.17	30.2	1.1
PE-2	Cal. Aqueduct @ Panoche T.O.#2	02/13/85	7.8	0.43	3.8	2.4	2.3	1.7	4.9	0.28	7.6	1.9
PE-2	Cal. Aqueduct @ Panoche T.O.#2	04/17/85	7.9	0.45	2.6	2.4	1.0	2.1	5.0	0.36	1.7	1.3
PE-2	Cal. Aqueduct @ Panoche T.O.#2	05/15/85	8.4	0.33	3.4	1.5	0.5	1.2	2.5	0.36	6.0	1.2
PE-2	Cal. Aqueduct @ Panoche T.O.#2	07/17/85	7.6	0.34	4.0	1.8	1.5	1.3	3.5	0.18	2.2	2.7
PE-2	Cal. Aqueduct @ Panoche T.O.#2	08/15/85	7.9	0.41	3.2	3.0	0.5	2.4	5.1	0.73	3.0	1.6
PE-2	Cal. Aqueduct @ Panoche T.O.#2	09/17/85	7.9	0.56	3.6	2.7	0.8	2.0	4.8	0.30	4.6	3.0
PE-2	Cal. Aqueduct @ Panoche T.O.#2	04/16/86	7.9	0.36	4.2	0.2	0.8	0.1	0.3	0.25	6.4	1.4
BV-2	Broadview Main Canal	01/29/85	7.7	0.44	5.0	2.7	0.5	1.7	3.9	0.45	10.0	8.5
BV-2	Broadview Main Canal	02/13/85	7.9	0.58	4.0	3.6	1.8	2.5	7.0	0.36	7.8	2.6
BV-2	Broadview Main Canal	02/28/85	7.6	0.74	4.8	2.9	0.4	1.9	4.1	0.62	5.0	14.5
BV-2	Broadview Main Canal	03/15/85	8.0	0.74	5.6	4.2	0.5	2.5	5.9	1.05	9.4	3.2
BV-2	Broadview Main Canal	04/02/85	8.0	1.20	8.6	6.7	1.2	3.2	9.3	1.36	16.8	4.3
BV-2	Broadview Main Canal	04/17/85	7.7	0.53	3.8	2.7	1.0	1.9	4.9	0.47	4.5	1.7
BV-2	Broadview Main Canal	04/30/85	7.7		4.0	1.9	0.5	1.3	3.0	0.63	5.6	1.2
BV-2	Broadview Main Canal	05/15/85	8.0	0.75	4.6	4.3	0.2	2.8	5.5	0.64	10.4	3.0
BV-2	Broadview Main Canal	06/03/85	8.3	0.46	6.0	2.4	2.0	1.4	4.1	0.34	8.8	4.6
BV-2	Broadview Main Canal	06/17/85	7.8	0.78	6.8	17.4	1.5	9.4	26.5	1.08	15.6	3.1
BV-2	Broadview Main Canal	07/01/85	7.9	0.64	3.4	3.4	1.5	2.6	6.9	0.50	9.2	1.8
BV-2	Broadview Main Canal	07/17/85	7.6	0.74	8.4	4.2	2.5	2.0	6.5	0.86	5.4	4.7
BV-2	Broadview Main Canal	08/02/85	7.5	1.78	10.2	10.5	1.2	4.6	13.6	1.40	13.0	6.4
BV-2	Broadview Main Canal	08/15/85	7.8	0.73	3.8	5.0	0.5	3.6	7.9	0.63	6.2	2.8
BV-2	Broadview Main Canal	09/03/85	8.7	0.50	4.0	2.7	1.0	1.9	4.7	0.34	1.0	2.6
BV-2	Broadview Main Canal	09/17/85	8.3	0.56	3.4	2.9	0.5	2.2	4.8	0.05	4.8	3.0
BV-2	Broadview Main Canal	10/22/85	8.1	0.60	5.0	2.9	1.0	1.9	4.8	0.21	5.4	3.1
BV-2	Broadview Main Canal	04/16/86	7.6	0.34	3.6	0.2	0.8	0.1	0.3	0.35	4.2	1.3
BV-2	Broadview Main Canal	07/17/86	7.6	1.08	7.0	5.7	2.5	3.0	9.2	0.74	11.8	4.0
BV-2	Broadview Main Canal	09/17/86	7.4	0.44	3.8	2.2	0.8	1.6	3.6	0.28	5.6	1.7
BV-2	Broadview Main Canal	10/27/86	7.8	0.67	5.8	3.2	0.5	1.9	4.3	0.41	5.8	2.5
BV-2	Broadview Main Canal	12/19/86	7.8	0.69	4.8	3.4	1.7	2.2	6.0	0.59	4.6	2.4
BV-2	Broadview Main Canal	07/03/87	7.9	1.34	10.6	7.2	1.0	3.1	8.7	0.90	6.8	4.9
BV-2	Broadview Main Canal	07/28/87	7.7	0.67	5.0	4.1	1.0	2.6	6.6	0.33	0.2	3.6
BV-2	Broadview Main Canal	09/03/87	8.1	0.51	3.8	2.9	0.5	2.1	4.5	0.17	1.6	2.7
GL-33	Mendota Pool @ Mowry Bridge	01/15/86	7.8	0.87						0.38		3.9
GL-33	Mendota Pool @ Mowry Bridge	02/20/86	7.0	0.24						0.15		0.6
GL-33	Mendota Pool @ Mowry Bridge	03/20/86	7.4	0.12						0.20		0.2
GL-33	Mendota Pool @ Mowry Bridge	04/16/86	7.1	0.17						0.20		0.3
GL-33	Mendota Pool @ Mowry Bridge	05/15/86	7.0	0.06						0.20		0.1
GL-33	Mendota Pool @ Mowry Bridge	06/17/86	6.7	0.37						0.29		1.5
GL-33	Mendota Pool @ Mowry Bridge	07/16/86	7.4	0.61						0.40		2.6
GL-33	Mendota Pool @ Mowry Bridge	08/14/86	7.5	0.53						0.48		1.9
GL-33	Mendota Pool @ Mowry Bridge	09/19/86	7.7	0.35						0.24		1.3
GL-33	Mendota Pool @ Mowry Bridge	10/27/86	7.7	0.32						0.31		1.5
GL-33	Mendota Pool @ Mowry Bridge	11/18/86	7.9	0.52						0.38		1.9
GL-33	Mendota Pool @ Mowry Bridge	12/19/86	7.7	0.42						0.27		
GL-33	Mendota Pool @ Mowry Bridge	01/16/87	7.9	0.52						0.57		1.6

E. SOILS

Figure 3 is based on the 1956 Mendota Area and 1952 Los Banos Area U.S.D.A. soil survey maps covering the study area. It should be noted that a more recent soil survey has been completed for the Los Banos Area. A new survey is under way for the Mendota Area which has not been completed. The two older maps were used because they were developed at approximately the same time and the soil series names are consistent from one to the other. The more recent surveys have sub-divided some of the soil series shown on the map into several different series.

The most abundant soil texture found in the study area is a clay loam. However, the textures range from sandy loams to clays. The soils can be classified in a more general way under the following categories:

(1) Soils of the Recent Alluvial Fans

(2) Soils of the Older Alluvial Fans and Terraces

(3) Soils of the Valley Basin Rim

The coloring of the soils map represents this general classification and helps one to understand the source of the parent material, the method of transportation and deposition, and the subsequent development of the soils in the study area.

Soils of the recent alluvial fans are primarily the Panoche, Panhill, and Sorrento series referred to in the older surveys and also includes the Excelsior, Westhaven, and some of the Ciervo and Cerini of the newer surveys. These soils are the result of recent (in geologic time) deposition of alluvial sediment and have not had time to develop strong horizons. Recent alluvial fan soils tend to be less saline than the other two categories.

Soils of the older alluvial fans and terraces consist primarily of the Lost Hills and Rincon series in the old surveys and the Deldota and Paver series in the new surveys. These soils occur on and near terrace areas next to the foothills where there has not been recent deposition of alluvial sediment because of geologic uplift. These soils have had more time to develop definitive horizons. These soils tend to be more saline than the recent alluvial fan soils.

Soils of the valley basin rim are primarily the Ortigaleta, Oxalis and Lethent series of the old surveys and the Chateu and some of the Ciervo and Cerini of the new surveys. These soils developed at the lower end of the alluvial fans where there was less frequent and sporadic sediment deposition. Also, these soils developed under poor surface drainage conditions and tend

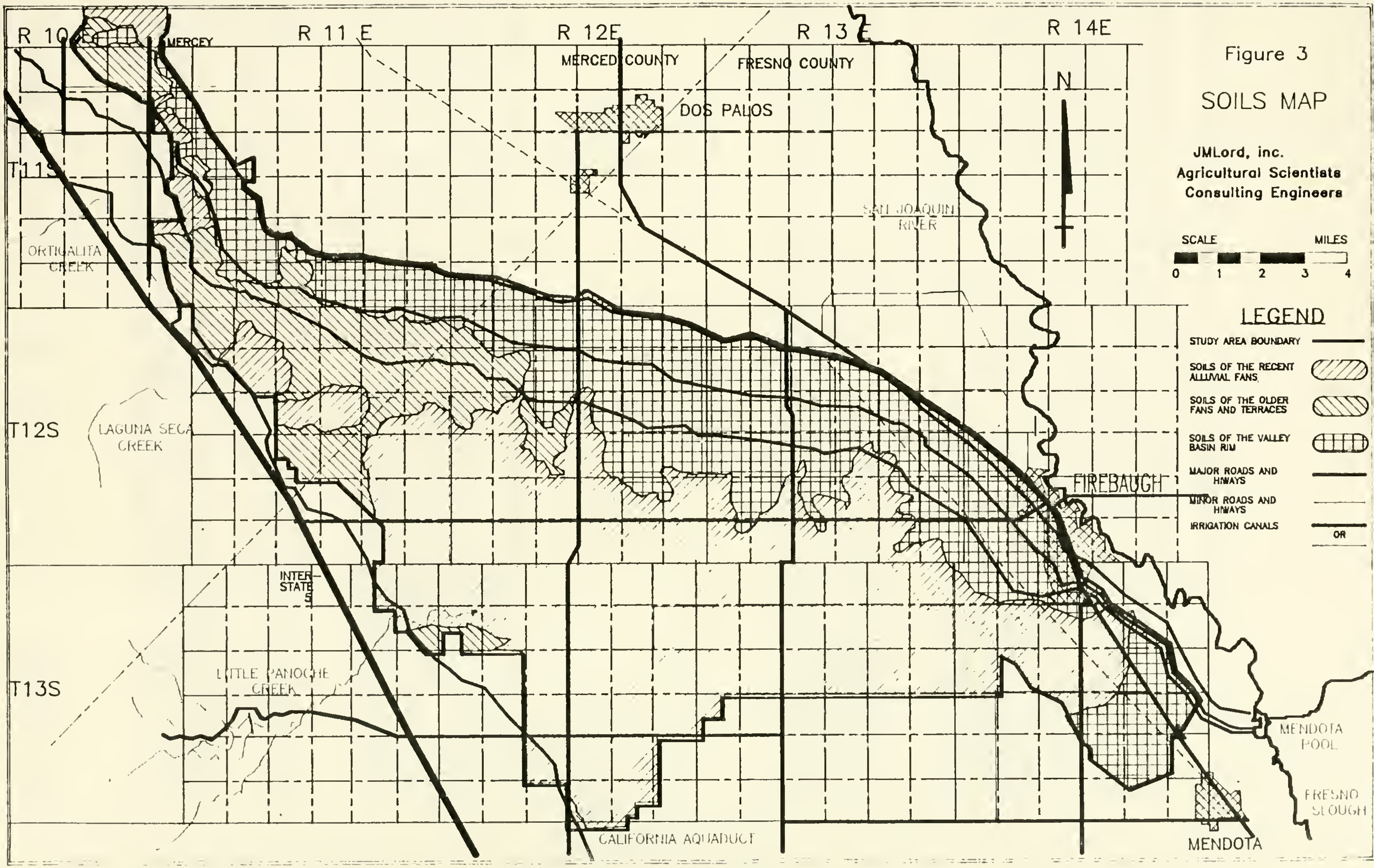


Figure 3

SOILS MAP

to be more saline than the other two soil categories.

A wide spread soil salinity survey in the drainage study area has not been done since the 1952 and 1956 soil survey. In those surveys, the average salinity over the depth of each test pit was given in terms of percent salt. Lines of equal percent salt were plotted using this data by Steve Deverell of the U.S.G.S. (unpublished) (Figure 4). This figure shows that the soil salinity corresponded very close to the soil categories mentioned above. The soils of the valley basin rim generally showed salinities in excess of 0.4% salt while the soils of the newer alluvial fans were generally less than 0.4 %. This figure covers only a small part of the area where the soils of the older alluvial fans and terraces are.

The conversion from percent salt to ECe (electrical conductivity of the saturated soil extract) can be approximated using a relationship given in the United States Salinity Laboratory's Diagnosis and Improvement of Saline and Alkali Soils (page 17). Assuming a saturation percentage of 50, the following conversion can be made:

Percent Salt	Approx. ECe (mmho/cm)
1.0%	31
0.8%	25
0.4%	12
0.2%	6
0.1%	3

When these figures are compared to salt tolerance tables for various crops, it can be seen that at the time of the soil survey, the salinity of most of the valley basin rim soils was above levels which cause yield reduction for even salt tolerant crops such as barley, wheat, cotton, and sugar beets. This suggests that at that time, leaching for reclamation purposes was needed on those soils. Of course, many years of irrigation and drainage have occurred since this survey and the present situation should be different.

More recent data on soil salinity in the drainage study area is very sparse. This should be rectified in the near future as the Soil Conservation Service (SCS) completes the new soil survey.

A search through JMLord, Inc.'s laboratory records found 15 fields within the drainage study area which had been analyzed for soil salinity profiles, to a depth of at least 3 feet, in the past 10 years. Results are presented in Table 3.

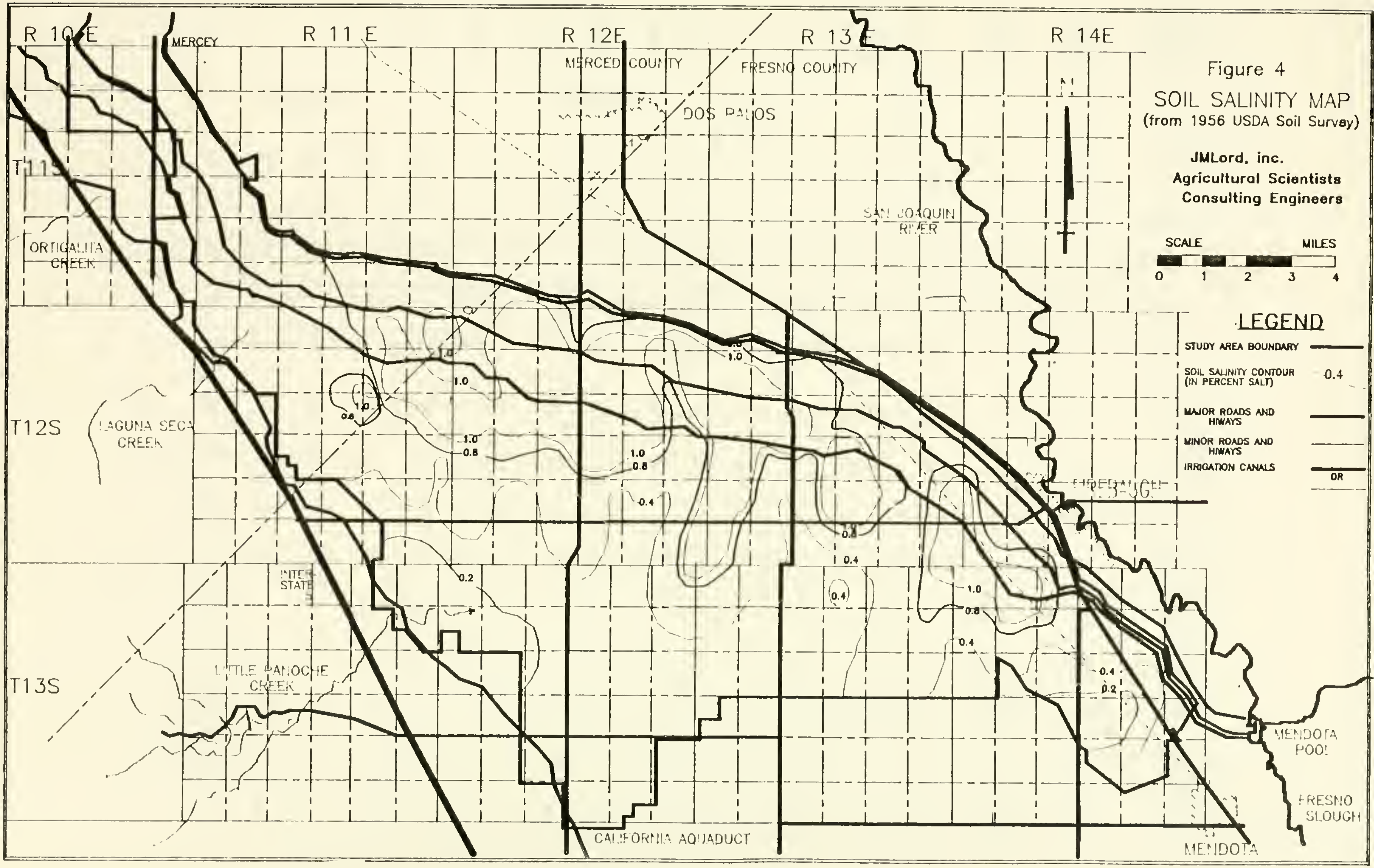


Figure 4

SOIL SALINITY MAP

(from 1956 USDA Soil Survey)

JMLord, inc.
Agricultural Scientists
Consulting Engineers

Table 3. Soil Salinity Analysis Results Within Drainage Study Area

Field	T.	R.	Sec.	Soil Series	Drained?	Year Sampled	Depth	ECe	SAR	Boron	Expected Yield Reduction Due to Salinity								
											Barley	Cotton	S. Beet	Wheat	Saffl.	Corn	Tomat.	Melons	Alfalfa
BF6	12S	11E	2	Oxalis & Lethent	No	1984	0-1	1.9	4.9	5.4									
							1-2	2.3	9.8	5.9									
							2-3	4.3	10.8	6.1									
							3-4	3.2	15.0	6.1									
							4-5	6.0	9.5	6.0									
						AVG.	....	3.5	10.0	5.9	0%	0%	0%	0%	0%	22%	10%	10%	11%
BF8	12S	11E	2	Oxalis & Lethent	No	1984	0-1	1.5	6.0	4.2									
							1-2	3.3	11.1	7.1									
							2-3	5.2	11.0	7.1									
							3-4	7.0	11.6	7.8									
							4-5	6.5	11.5	7.8									
						AVG.	....	4.7	10.2	6.8	0%	0%	0%	0%	0%	36%	22%	18%	20%
BF9	12S	11E	2	Oxalis & Lethent	No	1984	0-1	0.8	3.7	1.1									
							1-2	0.9	3.7	1.4									
							2-3	0.9	4.7	1.4									
							3-4	0.9	4.3	1.4									
							4-5	1.1	4.9	1.5									
						AVG.	....	0.9	4.3	1.4	0%	0%	0%	0%	0%	0%	0%	0%	0%
HR15-1	13S	12E	15	Panoche	No. tiled in 1983	1982	0-1	1.5	3.7	0.8									
							2-3	4.8	14.0	3.6									
						AVG.	....	3.2	8.9	2.2	0%	0%	0%	0%	0%	17%	6%	7%	8%
HR14-1	13S	12E	14	Panoche	No	1982	0-1	1.4	4.2	0.9									
							2-3	2.6	9.2	2.7									
						AVG.	....	2.0	6.7	1.8	0%	0%	0%	0%	0%	4%	0%	0%	0%
HR22-3	13S	12E	22	Panoche	No	1982	0-1	0.9	3.3	0.6									
							2-3	0.9	6.1	0.7									
							4-5	0.9	7.2	0.8									
						AVG.	....	0.9	5.5	0.7	0%	0%	0%	0%	0%	0%	0%	0%	0%
HR22-3A	13S	12E	22	Panoche	No. tiled in 1983	1982	0-1	0.8	2.8	0.7									
							2-3	1.0	7.1	1.2									
							4-5	5.3	8.5	3.3									
						AVG.	....	2.4	6.1	1.7	0%	0%	0%	0%	0%	8%	0%	1%	3%
DJ4	12S	12E	3	Lethent	No	1982	0-2	9.2	17.6	7.9									
							2-4	10.4	22.9	7.9									
						AVG.	....	9.8	20.3	7.9	9%	11%	18%	27%	49%	96%	72%	55%	57%
DJ8	12S	12E	3	Lethent	No	1982	0-2	9.8	17.3	4.9									
							2-4	14.7	30.1	6.8									
						AVG.	....	12.3	23.7	5.9	21%	24%	33%	45%	76%	126%	96%	73%	75%
GD157	12S	12E	30	Panoche	Yes (tiled after 1975)	1981	0-1	0.8	1.9	1.1									
							1-2	1.0	2.6	1.5									
							2-3	1.7	4.0	2.1									
						AVG.	....	1.1	2.8	1.6	0%	0%	0%	0%	0%	0%	0%	0%	0%
GD157P	12S	12E	30	Panoche	Yes (tiled after 1975)	1981	0-1	4.3	7.6	7.0									
							1-2	7.5	13.0	7.6									
							2-3	7.4	12.1	6.5									
						AVG.	....	6.4	10.9	7.1	0%	0%	0%	3%	12%	56%	38%	30%	32%
JF20	11S	11E	18	Orestimba	Yes	1980	0-1	0.6	1.5	0.7									
							1-2	0.6	2.9	1.5									
							2-3	3.6	2.8	2.9									
							3-4	4.6	3.9	3.9									
						AVG.	....	2.4	2.8	2.3	0%	0%	0%	0%	0%	8%	0%	1%	3%
JF20	11S	11E	18	Orestimba	Yes	1981	0-1	0.7	1.6	0.4									
							1-2	0.6	1.8	0.6									
							2-3	0.6	2.2	0.7									
							3-4	0.7	3.7	1.1									
						AVG.	....	0.7	2.3	0.7	0%	0%	0%	0%	0%	0%	0%	0%	0%
JJ14-4	13S	14E	22	Oxalis	No	1979	0-1	3.0	6.4	2.2									
							1-2	5.2	10.7	3.8									
							2-3	8.1	16.8	6.2									
						AVG.	....	5.4	11.3	4.1	0%	0%	0%	0%	1%	44%	29%	23%	25%
JJ19-6	13S	14E	27	Oxalis	Yes (tiled 1977)	1979	0-1	2.7	5.1	1.5									
							1-2	5.5	10.3	3.5									
							2-3	7.4	14.5	5.1									
						AVG.	....	5.2	10.0	3.4	0%	0%	0%	0%	0%	42%	26%	22%	24%
JJ24-7	13S	14E	26	Oxalis	Yes (tiled 1978)	1979	0-1	1.5	4.3	1.5									
							1-2	4.3	11.3	4.0									
							2-3	7.4	17.7	6.3									
						AVG.	....	4.4	11.1	3.9	0%	0%	0%	0%	0%	32%	19%	16%	18%
JJ13E-3	13S	14E	23	Oxalis	No	1979	0-1	2.0	4.7	1.0									
							1-2	2.9	10.7	1.9									
							2-3	6.5	17.1	3.8									
						AVG.	....	3.8	10.8	2.2	0%	0%	0%	0%	0%	25%	13%	12%	13%

The data shown in the table is not necessarily representative of the whole drainage study area, but does shed some light on the current salinity status of the area. Fields BF6, 8, and 9 were within the same section with the same soil series. None of them had tile drains. Two of these fields had ECe levels which would reduce yields to the more salt sensitive crops, but the third did not. HR15-1, 14-1, 22-3, and 22-3A were all sampled before any tile drains were installed. Three of the four fields had salinity levels high enough to cause small yield reductions in the more sensitive crops. Fields DJ4 and DJ8 were within the same section and neither had tile drains. The average root zone ECe was very high for both fields and yield reductions to salt tolerant crops could be expected. Field GD157, which had tile drains, was sampled as a whole by walking a diagonal line across the field and compositing 10 to 15 soil probe cores (this is the standard method JMLord, Inc. uses to sample for salinity profiles). The analysis showed very little soil salinity buildup. However, a portion of the same field where poor crop growth was observed was sampled separately (GD157P) and showed a significant soil salinity buildup. This shows the variability of soil salinity which can occur within the same field. Field JF20, which has tile drains, was sampled in 1980 and again in 1981. The first sampling showed some buildup of salts and Boron in the third and fourth foot. The following year however, the salt and Boron levels were much lower. This shows the variation which can occur from year to year. Fields JJ14-4, 19-6, 24-7, and 13E3 are all within a mile of each other. They had similar salinity and boron levels, high enough to reduce yields on the more salt sensitive crops. Two of the fields had tile drains installed less than two years before the sampling while the others did not have tile drains.

The limited soil salinity data available shows that some areas of the drainage study area which are already in production may require leaching for reclamation purposes, especially where salt sensitive crops are grown. The extent of the need for reclamation is not known but should not be neglected when considering drainage reduction programs.

F. SUBSURFACE DRAINAGE WATER QUALITY AND QUANTITIES

Information on the quality and quantity of water coming out of subsurface drainage systems in the drainage study area is more abundant than on the soils. Not all of the subsurface drainage systems have been or are being monitored, however. Even the drains being monitored have different sampling intervals and lab analysis by the various entities. In order to make sense of the data available, histograms were prepared to show the statistical distribution of the quality and flow data observed from the available data. These are presented as Figures 5 through 8.

FIGURE 5 Annual Flow Histogram

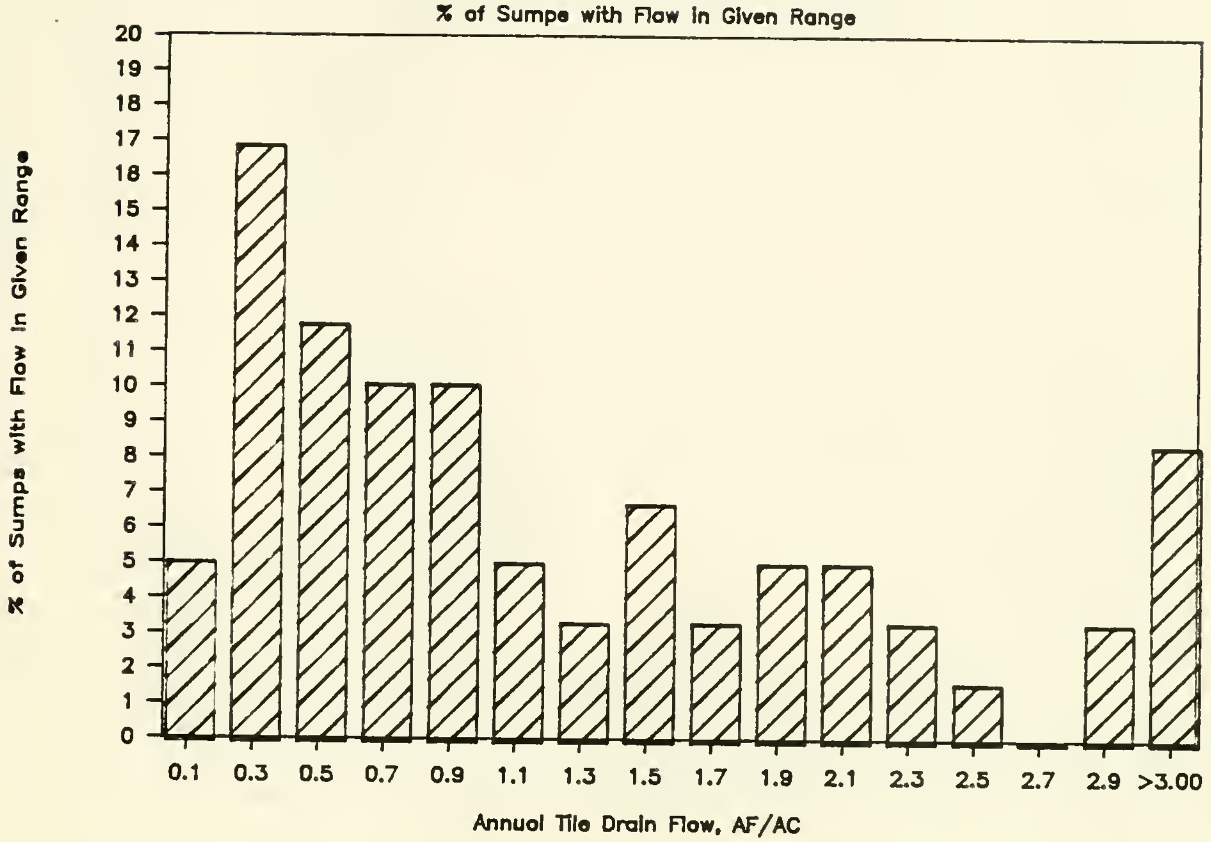


FIGURE 6 EC Histogram

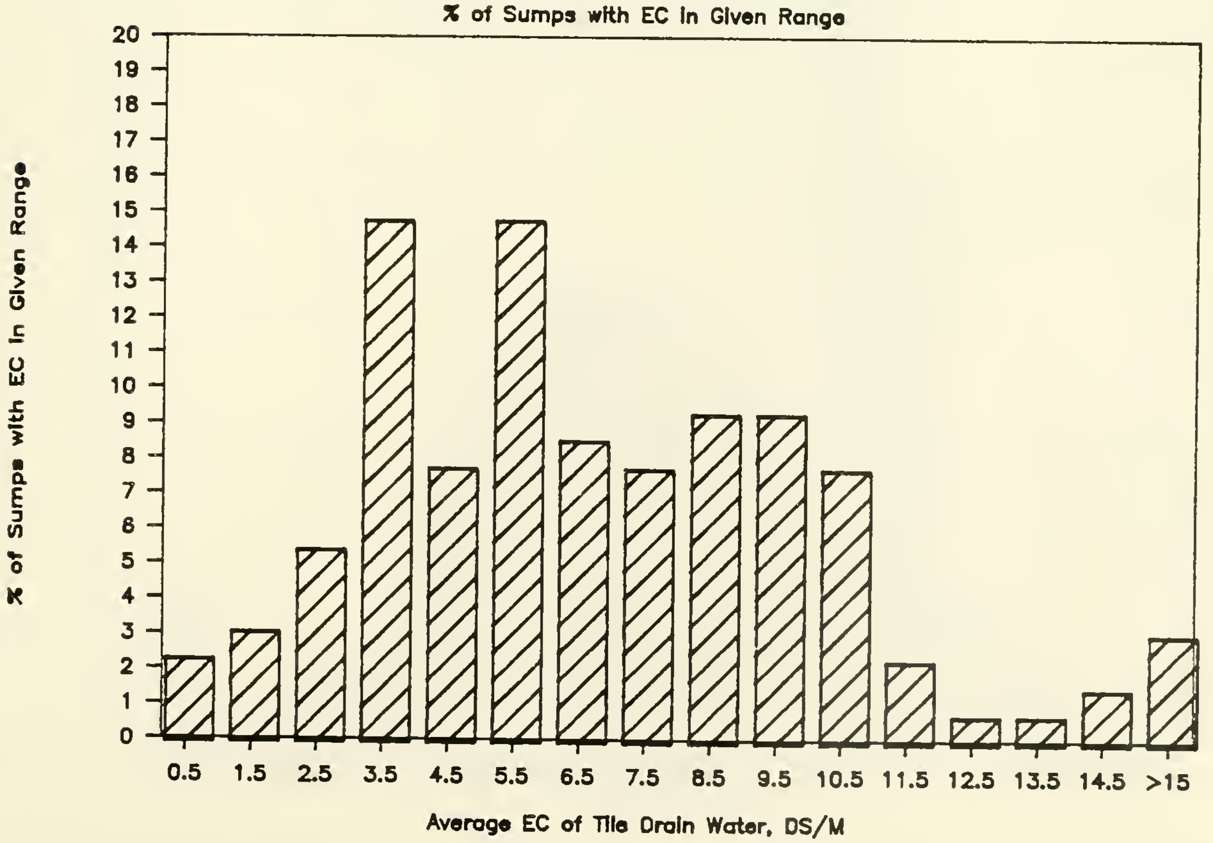


FIGURE 7 Boron Histogram

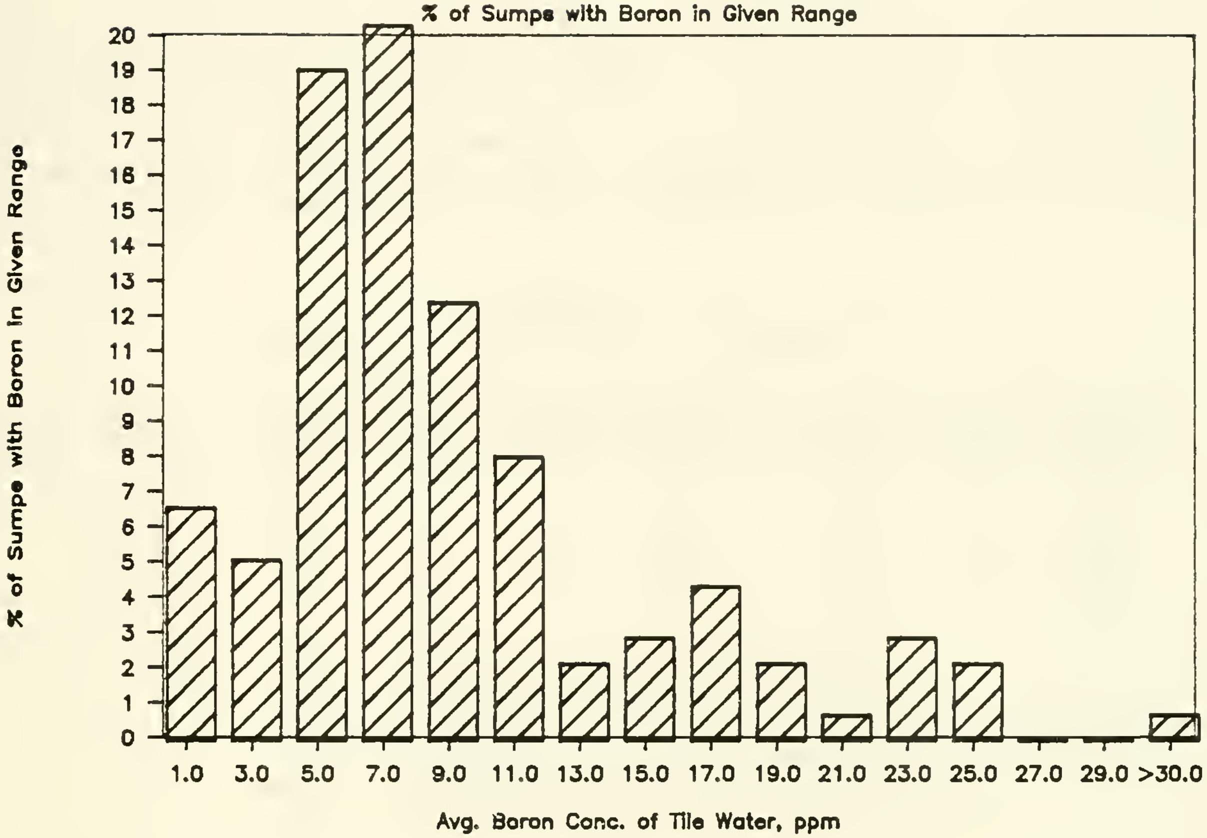
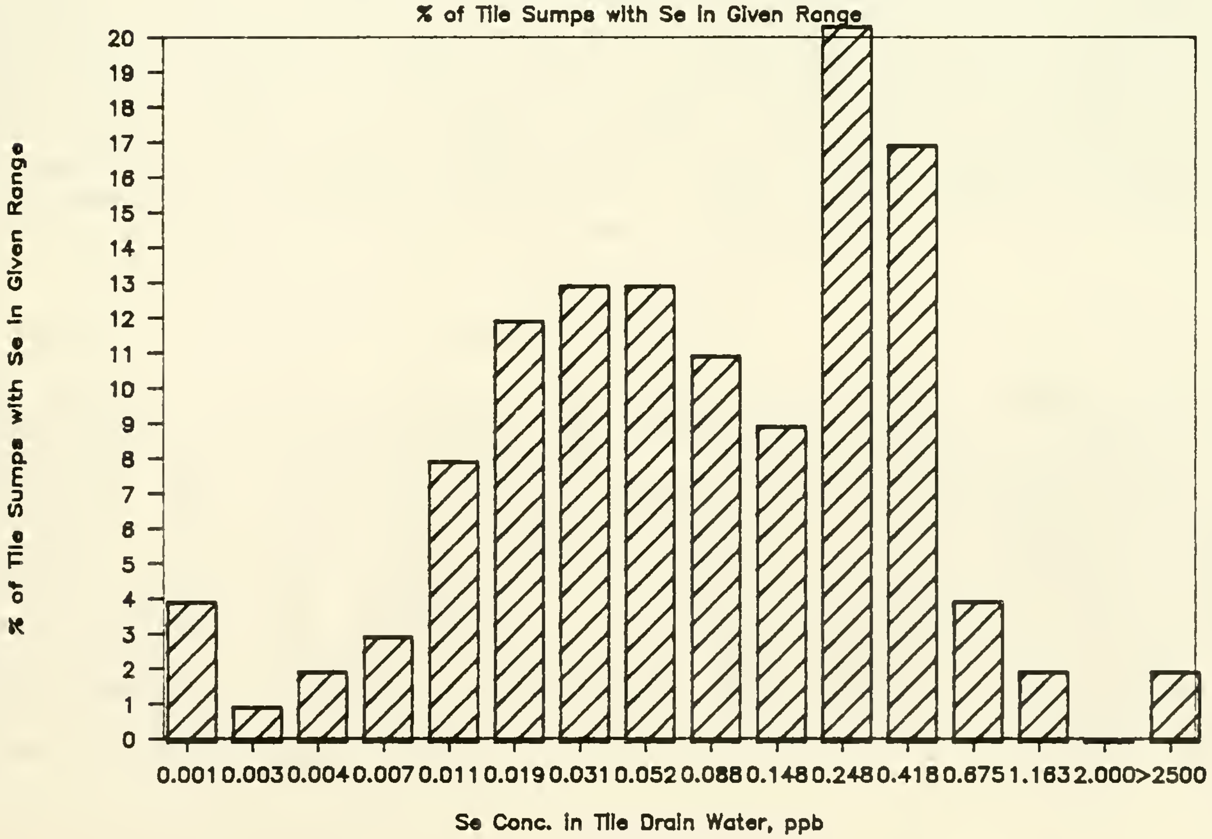


FIGURE 8 Selenium Histogram



These figures show the percent of the tile outlets monitored which had an annual flow, average EC, boron, or selenium concentration in the given range. Because of the differences in the monitoring programs from district to district, the sample population was not the same in each of the figures. This will have an affect on the shape of the frequency distribution. The following table shows the sample population represented in each figure.

TABLE 4.
SAMPLE POPULATIONS FOR HISTOGRAMS

		Number of tile outlets sampled in each district							
Figure	Meas.	PDD	BVWD	CCID	FBCC	CDD	PWD	NONE	TOTAL
5	Flow	14	25	17	3	0	0	0	59
6	EC	45	23	18	29	5	5	2	127
7	Boron	46	0	18	30	5	5	2	106
8	Se	46	21	17	30	5	5	2	126

where: PDD = Panoche Drainage District
BVWD = Broadview Water District
CCID = Central California Irrigation District
FBCC = Firebaugh Canal Company
CDD = Charleston Drainage District
PWD = Pachecho Water District

It is important to realize that the quantity of water coming from a subsurface drainage system is usually not equal to the amount of deep percolation from rain and irrigation on the field(s) drained. Seepage from canals and ditches, upflow from underlying strata, and lateral inflow can all increase the flow from the subsurface drains. Likewise, water seeping below the tile drains, improperly functioning drains and lateral outflow can decrease the subsurface drain flow. All of these phenomena have been observed to varying degrees in the study area. A more detailed discussion of this follows in section VIII.

G. EXISTING SUBSURFACE DRAINAGE SYSTEMS

Information on the layout (location, placement depth, pipe slope), year of installation, and materials used is also very spotty in the drainage study area. The Regional Water Quality Control Board gathered what information the drainage and water districts had on the subsurface drainage systems in their areas in 1984. These districts, however, could not get information on all of their tile systems. J.B. Summers, Inc. produced a map based upon the same information in the Grassland's Task Force Study (1986). Figure 1 shows the areas which have subsurface drains based upon Summer's map with modifications where addi-

tional information was available.

The first tile drains installed in the study area were within the Firebaugh Canal Company in 1951. These consisted of red clay tile pipe, laid behind a trencher, with open butt joints which were covered on top with tar paper and surrounded with a gravel envelope material. Open joint concrete pipe with a gravel envelope was the main material used from the mid 1950's until around 1970. At that time, corrugated perforated plastic pipe and gravel envelope became the predominant construction materials. Experiments with other pipe and envelope materials were done by many growers in trying to reduce the installation costs. Materials tried include tar paper pipe, fiberglass wrapped pipe, oval plastic pipe, mole drains, sand envelope, and fiberglass fabric envelope.

Tile systems in the drainage study area have been designed by the SCS, drainage contractors, pipe companies, consultants, or by the farmers themselves. Many different contractors have installed systems over the years. Consequently, it is not surprising that good as-built drawings of many of the drainage systems were never prepared or have subsequently been lost.

Information on the existing tile drainage systems is very important for designing the hardware and management requirements for a drainage reduction program. The lack of good records for many of the existing tile systems will make the job more difficult. Usually it will require probing and excavation to map the systems. How well a drainage system is working (e.g. Is it plugged, collapsed, or silted in) is a further complication to the planning and implementation of a drainage reduction program.

III. IRRIGATION AND DRAINAGE MANAGEMENT THEORY AND PRACTICE

A. IRRIGATION SCHEDULING AND SWAP/ET

1. Fields without shallow water table

Irrigation scheduling enables growers to determine the proper time and the proper amount of irrigation water needed to meet the crop's water needs. This process or technique is, however, a difficult and critical management decision, both from an economic and operational aspect. Delayed irrigations impose undue plant stress which reduce crop yields. Irrigations in excess of plant water requirements waste both manpower and water which increase production costs and can create or add to perched water table problems or excessive drainage flows. In other words, irrigation scheduling enables growers to correctly answer two difficult and crucial questions: When should I irrigate a particular field, and how much water should I apply?

The basis of this report's irrigation scheduling is a computerized model known as SWAP/ET, which has been used successfully on more than 800,000 acres of irrigated crop land.

The SWAP/ET program is a soil based, water budget program which utilizes soil, water, atmospheric, and plant parameters to accurately predict the date of an upcoming irrigation and determine the amount of water required for that irrigation. Hence, SWAP/ET is a predictive program which enables growers to plan for upcoming irrigations and schedule labor and water accordingly. A brief explanation of the SWAP/ET program is presented in the following paragraph.

In general, a soil based water budget model, such as SWAP/ ET, balances water additions (i.e., irrigations and rain fall) against withdrawals (i.,e., evapotranspiration). When withdrawals exceed a critical maximum value, the amount of stored water remaining in the soil profile is insufficient to meet plant evapotranspiration demands. Plant stress and reduced yields result if water is not applied at this time. Daily potential evapotranspiration (ETp) is calculated from weather data (i.e., solar radiation, wind run, maximum and minimum temperature, and dew point) using a modified Penman method. ETp is multiplied by a crop coefficient to obtain daily evapotranspiration (ET), which is the amount of water withdrawn by the roots from the soil profile.

The available water holding capacity of a soil (AWHC), expressed as inches of available water per foot of soil, is principally determined by soil texture and represents the quantity of water held between field capacity (1/3 bar of suction) and permanent

wilting point (15 bars of suction). Typical values range from less than 1 inch of water for a sandy soil to 2.5 inches for heavy textured or clay and silt dominated soils. However, the majority of plant available water is held at low suction (near 1/3 bar). As suction increases, plant roots extract water with increasing difficulty. The ability of a soil to give up water is usually shown with soil moisture release curves. During periods of high water demand, plants can exhibit stress even though the total matrix potential is less than the permanent wilting point. Therefore, irrigations are scheduled when a designed portion of the soil available water has been extracted. In the SWAP/ET program, this value is referred to as the management allowable depletion (MAD). Equally important, an effective scheduling program will allow the grower to utilize his rootzone reservoir so that the field is irrigated when this reservoir is at a moisture depletion level that is best suited to his irrigation method.

Crops differ in their ability to extract plant available water, and, therefore, different MAD's are used. The MAD will also vary with salinity, crop type, growth stage, and irrigation method. The MAD for a given crop will vary between 30% (for potatoes) and 60% (for small grains). The MAD value can be changed during the growing season to reflect periods when water stress is particularly injurious to crop yields. For non-saline soils or irrigation water, the MAD value will be based only on the matric potential, or soil moisture release curve. For saline situations, there is an additional potential, called the osmotic potential, that the plant roots must overcome to obtain water. The MAD value for these situations is necessarily lowered in proportion to the level of salinity in the root zone.

Irrigation and rainfall represent inputs to the soil water budget model. The quantity of water applied is determined by direct measurement, or, by probing the soil following an irrigation event to determine the residual soil moisture status. The amount applied is then calculated based on the soil's AWHC and soil depletion (example: AWHC of 2 inches per foot of soil, 50% of the AWHC was depleted at the time of irrigation, probing revealed a 4 foot average depth of water penetration; therefore, the quantity of water applied was 2 X 50/100 X 4 = 4 inches).

In order to help visualize how the SWAP/ET program functions, a brief explanation of implementing the SWAP/ ET program for a hypothetical field will be given. Prior to planting, the field is probed and sampled to determine soil texture at one foot increments to the depth of the pending crop's root zone. This procedure is used to establish AWHC for each one foot depth increment, and, through laboratory analysis, reveal any potential salinity hazard. Salinity, crop type and growth stage are then used throughout the crop season to determine the MAD percentage for each successive irrigation. Also during the growing season,

daily weather data is entered periodically, usually twice a week, into the SWAP/ET program. Based on irrigations and the calculated daily ET, the SWAP/ET program determines the current soil moisture depletion. The next irrigation date is then based on this depletion and the forecast ET, which is based on a combination of the historical ET, the projected crop growth factor, and the crop's current MAD. Calculated soil moisture depletions are verified through field checking. Field soil moisture depletions are determined by the "feel" method. If the calculated soil moisture depletion differs from the field depletion, the latter is entered into the computer and a new irrigation date is forecast. As described earlier, irrigation quantities are determined following each irrigation, and the entire process is repeated for each irrigation interval throughout the growing season.

Scheduling irrigations with the SWAP/ET program has worked accurately and effectively on fields without shallow water table. However, because the program does not consider the contribution from a shallow water table on crop ET, it tends to over-predict soil moisture depletions, and therefore irrigations, when shallow water tables influence the crop root zone.

2. Fields with shallow water table

Fields with shallow water table pose special problems in irrigation scheduling. In the past, scheduling irrigations on water table affected fields with SWAP/ET or any other soil based water budget method was as much art as science. This was because the amount of water moving upward from the water table into the root zone varies greatly from one field to another and throughout the growing season. To compensate for the influence of the water table, fields were checked more frequently and estimates of the water table contribution to crop ET (WT) were used to reduce the crop coefficient to make the predictions of soil moisture "track" better with what was being observed in the field.

Since the key to proper irrigation scheduling on fields with shallow water table is predicting the WT, published literature was reviewed concerning the subject. The literature review revealed that the WT can vary from 4% to 93% (Stuff and Dale, 1978; Kruse, et al., 1986). This large variability occurs because of the host of soil, plant, chemical, irrigation, and spatial factors which affect a crop's ability to utilize water from a shallow water table.

Specifically, the primary factors which have been found to influence WT include water table depth, root zone depth, root zone depletion, vertical unsaturated hydraulic conductivity (which varies with soil type), salinity of the water table, and crop type. The conditions under which research has been done to estimate WT values has varied considerably. There is therefore

no one table or figure available from which a number can be taken and inserted into the SWAP/ET program for the amount of the daily WT for the given conditions. The closest thing to this is the work done by Grismer and Gates. (1987). Figure 9 shows, from a combination of several researcher's data, the percent of water table contribution to seasonal ET for a given depth to water table for cotton. Data from Grimes et. al. (1984) shows that the daily or weekly WT can be over 100% different from the seasonal average. In the few published articles dealing with the seasonal variability of water table contribution, there are big differences in reported WT during different times of the year. For example, Hanson and Kite (1984) reported the WT for cotton was highest in the first half of June and the first half of September, but was at a minimum in July in two of three test fields. However, Namken et al (1969) reported that the WT for cotton was insignificant in April but increased to a maximum in July.

In the interest of finding a way to predict the daily, weekly, or monthly WT, a look was made into the influence that each of the following primary factors has.

a. Water table depth and root zone depth

Depth to water table and root zone depth are interrelated factors which influence WT. As the distance between the bottom of the root zone and the top of the water table decreases, the contribution of the water table to consumptive use will increase. This is because the energy gradient which drives the upward flux of water increases with decreasing distance between the two. Namken (1969) found average seasonal WT's for several different irrigation treatments of 58, 38, and 28 percent for cotton grown on static water tables at depths of 91, 183, and 74 cm, respectively. Chaudhary, et al. (1974) working with wheat calculated WT values of 70, 53, 27 and 20 percent for static water tables at depths of 60, 90, 120 and 150 cm respectively. Crops which develop deep root zones earlier in the growing season will usually have a greater WT. If the distance between the bottom of the root zone and the water table level stays about the same, in cases where the root zone is expanding as the water table is falling, the WT would be expected to stay relatively steady.

b. Root zone depletion

The drier the root zone soil is, the greater the WT will be. This is because the energy gradient which drives the upward flux is created by the moisture gradient. Therefore, the dryer the soil in the root zone is allowed to become between irrigations, the greater is the upward flux from the water table into the root zone. The rate of evapotranspiration (ET) will affect the amount of upflux from the water table because it will change the dryness of the root zone. The irrigation practices used on a given field

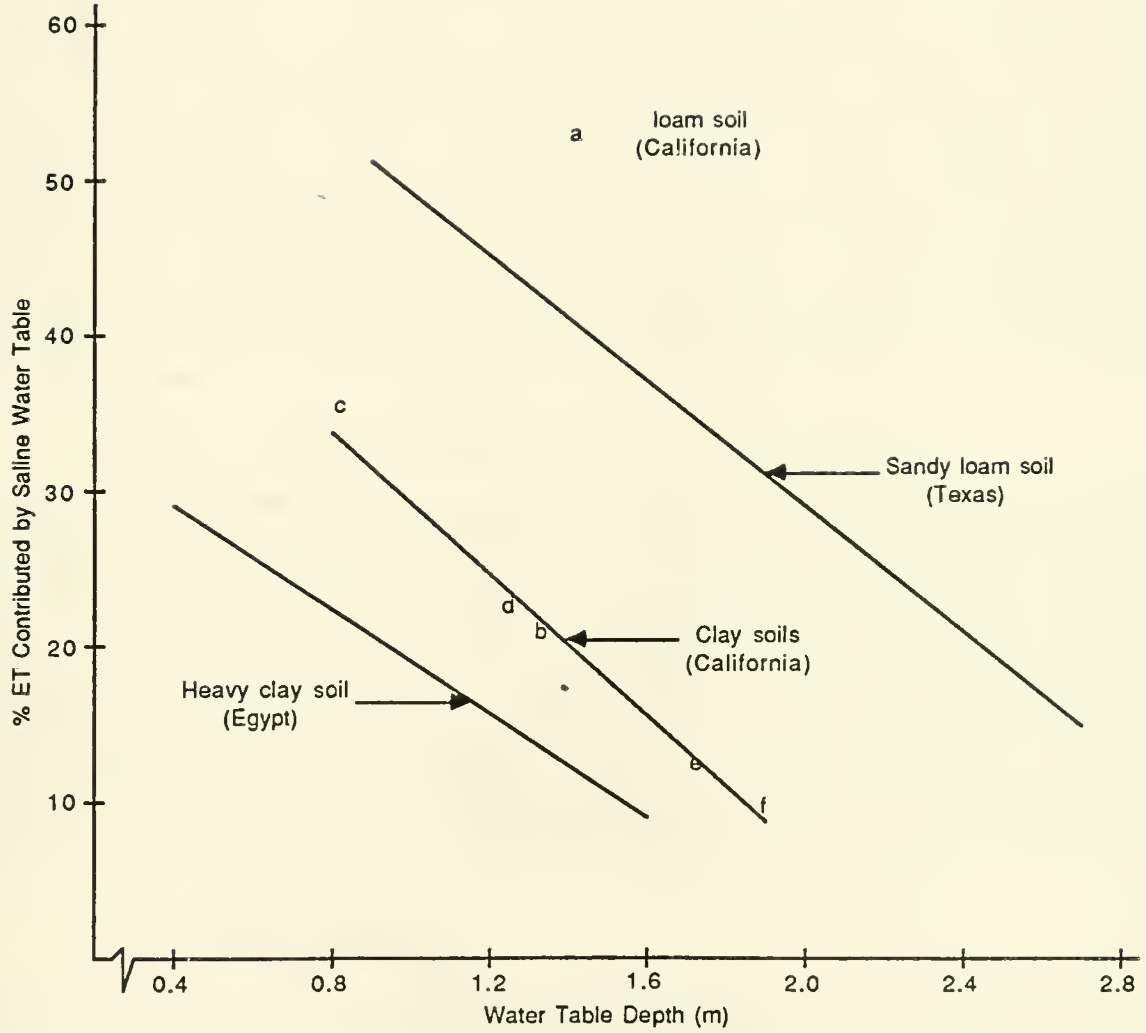


Figure 9. Contributions (%ET) of saline water tables to cotton water use as affected by water table depth (for explanation of letters, see Table 1).

Source: Grismer and Gates (1987)

(interval between irrigations and amounts applied) will also influence the WT. In general, the WT decreases as irrigation frequencies and/or amounts increase (Wallender, et al., 1979; Namken, et al., 1969; Benz, et al., 1985 a,b).

The moisture extraction pattern from the soil profile may also influence the amount of WT. Plants will tend to extract different amounts of soil moisture from different levels of the root zone. This is partly due to the fact that typical crop rooting densities decrease with increasing soil depth. The upper most depth increment will therefore contribute a significantly larger percentage of the total plant water requirement than the next deeper increment, and so on. Ferry, et al. (1980) reported root zone soil water use of cotton to be 42, 30, 18, and 10% from the top 1/4, 2/4, 3/4, and 4/4 of the root zone, respectively. Since crops respond dynamically to changes in their environment, moisture extraction patterns will change through the season as soil moisture profiles, climatic demand patterns, salinity, and the crop growth stage change.

c. Vertical unsaturated hydraulic conductivity

The vertical unsaturated hydraulic conductivity of the soil that the water flowing upward from the water table must pass through also influences the amount of WT. Generally, soils with low vertical unsaturated hydraulic conductivity values will have lower values of WT. The vertical unsaturated hydraulic conductivity is a function of the pore size and distribution in the soil. Generally, sandy soils will have higher values of unsaturated hydraulic conductivities than clay soils. Skaggs (1978) shows curves of maximum upflux from a water table for different soil types in the Eastern United States. The curves should not be used for Western soils, but do illustrate the affect soil texture has on upflux from a water table.

d. Water table salinity

Salts in soil water make it harder for plant roots to extract water. Increasing concentrations of salts in shallow ground water, as measured by its electrical conductivity (EC), have been found to reduce the WT. The reduction, however, is not consistent, but varies with crop type. Salt resistant crops, such as cotton, are able to extract water at much higher salinities than salt sensitive crops and only very high salinities reduce the contribution to ET. Hanson (1987) reported a 30% maximum contribution from a shallow water table (5 foot) with an EC of 10 ds/m. Namken, et al. (1969) observed a decrease in water table contribution to ET as salinity increased.

Caution must be used when saline groundwater contributes to consumptive use because of the accumulation of salts in the upflux zone. If these salts are not periodically leached from

the root zone, salinity levels injurious to crop yields can be reached. Wallender, et al. (1979) found a much higher soil salinity level in the saline water table capillary zone (EC of 7.9 ds/m) than in the soil zone immediately above it (EC of 3.1 ds/m). Namken (1969), working with water tables with EC's of less than 2 ds/m and greater than 6 ds/m, found a much greater salt build up in the water table capillary zone for the more saline groundwater regardless of depth to water table or irrigation treatment. Meed, et al. (1980), and Chaudhary, et al. (1974) have also shown the affect salinity has on WT.

e. Crop type

Research has shown different WT's for different crops. These differences can probably be explained because of differences in the rate and extent of development of the root zone, types of rooting system, salt tolerance, and irrigation management employed. It is not known if there is another factor which makes the WT different for each crop with the other parameters being the same.

Because of the myriad of factors which influence WT, and the complex interaction between the various factors, we have concluded that a model which accounts for all of these factors is the only effective way to schedule irrigations when a shallow water table is a factor.

B. IRRIGATION EVALUATION

Surface irrigation is the primary irrigation type in the drainage study area. Capital costs for surface irrigation are less than for other irrigation types in the study area. Although surface irrigation can be done efficiently in a well conceived and managed situation, it is difficult to precisely control the amount of water which will infiltrate into the ground.

Surface irrigation presents challenges to the designer and operator that do not exist in sprinkler or drip systems, since the soil surface is used as the conveyance medium for distributing the water throughout the field. The hydraulic properties of this medium are not as well understood and cannot be as well defined as those of a pipeline or other conduit. To further compound the problem, the soil condition is constantly changing. Each irrigation, cultivation, soil moisture content, and temperature affect the way water moves into and over the soil. These factors make it unlikely that a system will be operated as efficiently as possible without an evaluation of the conditions at the time of each irrigation event.

As in any type of irrigation, the two major components of inefficient water use are deep percolation and lost runoff

(tailwater). Tailwater runoff contributes to the subsurface drainage problems in the study area in a minor way relative to what deep percolation does (for example, seepage from tailwater collection pits or drains). For this reason, efforts to reduce subsurface drainage volumes in this report are focused on reducing the amount of deep percolation. The tailwater component should not be overlooked, however. When subsurface and surface drainage waters are not collected separately and must be treated before discharge, the cost advantages of subsurface drainage reduction can be lost if surface drainage is increased.

The goal of each surface irrigation event is to infiltrate a volume of water in the least irrigated portion of the field that is equal to the soil moisture deficit plus the leaching requirement. The least irrigated portion of the field is often called the low quarter. The low quarter is defined as that 25% of the field area which receives the least amount of water. In surface irrigation, the low quarter of the field is often the last quarter of the field's length at the tail end of the field since water does not stand on the surface as long there. In some situations, such as with blocked furrows, or with variable soils or traffic patterns, this is not necessarily the case.

An additional goal in the irrigation is that the water should be distributed uniformly across the field. This idea of uniformity has been quantified by the term distribution uniformity (DU) which is defined as the average depth infiltrated in the low quarter divided by the average depth infiltrated over the entire field. Application efficiency (AE) is defined as the depth of water stored in the rootzone divided by the total depth applied.

The solid curved line in Figure 10 shows a typical over irrigation down the length of a furrow with a DU in the low 70% range. The curved dashed line indicates the desired condition with a much higher DU (DU = 90%). The characteristics of surface irrigation make it impossible to infiltrate exactly the same depth of water over the whole length of a furrow or border (DU = 100%). However, on a field of uniform slope and soils, it is not unreasonable to produce a DU above 80% with the proper design, management, and operation.

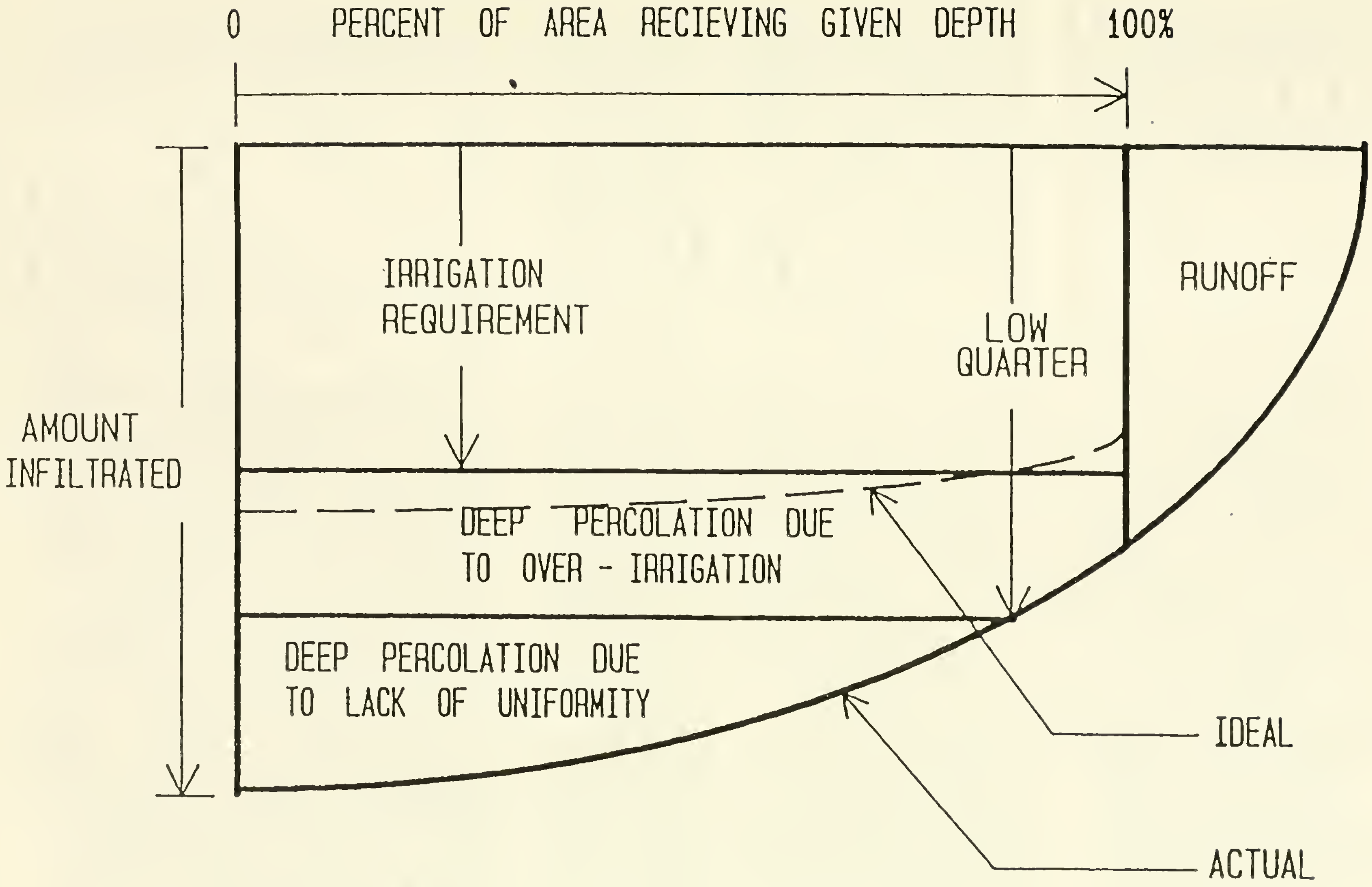

0
PERCENT OF AREA RECIEVING GIVEN DEPTH
100%
AMOUNT INFILTRATED
IRRIGATION REQUIREMENT
LOW QUARTER
RUNOFF
DEEP PERCOLATION DUE TO OVER - IRRIGATION
DEEP PERCOLATION DUE TO LACK OF UNIFORMITY
IDEAL
ACTUAL

Figure 10 Typical Water Destination Graph

There are two components of the deep percolation. The first is the amount of deep percolation due to over-irrigation of the field (the whole field receives more than the irrigation requirement). This can sometimes be reduced during the growing season by postponing an irrigation to develop a higher irrigation requirement, or by shortening the time that water is applied to the furrow or border (set time). During pre-irrigations or first seasonal irrigations on the west side of the San Joaquin Valley, often the initial intake rate of the soil is so high that it becomes nearly impossible to control the amount infiltrated in the low quarter to match the irrigation requirement and still make the water advance to the end of the field.

The second component of deep percolation is that portion due to a poor distribution uniformity. Poor distribution uniformity may be the result of system limitations or poor management. The DU can often be improved by increasing the furrow or border flow rate to speed the water's advance and/or by increasing the set time. The DU can also be improved by changing the furrow length or by utilizing cutback or surge irrigation techniques. However, in all of these sophisticated approaches to furrow irrigation, an inherent difference in the total water infiltrated will exist between the upper and lower ends of the furrow due to a difference in the time of exposure to water.

A tool to accomplish the reduction of deep percolation from a single irrigation event is to conduct an irrigation evaluation. By evaluating the pre-irrigation, first seasonal irrigation, and a third or later irrigation, an irrigation consultant can suggest the best management strategy for each situation that may greatly reduce the deep percolation due to both over irrigation and lack of uniformity.

An irrigation evaluation consists of a visit to the field, during the irrigation in question, by the irrigation consultant. Data such as furrow flow rates, advance rates, furrow profiles and lengths, the furrow type (wheel row, non-wheel row), soil moisture deficit and field slope are taken. These data are then used to mathematically model the given irrigation. Once this is accomplished, factors such as the furrow flow rate and furrow length may be varied to determine the management needed to obtain the best possible distribution uniformity and application efficiency. The consultant can then tell the irrigator the best way to adequately irrigate the field. In order to accomplish the goal of reducing deep percolation, the analysis and recommendations must be processed and relayed to the irrigator in time to implement them on most of the field and the irrigator must be willing to try the recommended changes. Frequently, labor limitations (such as no night irrigators) or lack of a means of handling runoff (blocked furrows) will eliminate some options from being implemented during the same irrigation.

In fields where shallow water table contributes to the crop ET, the deep percolation from each irrigation and rainfall event should not be added together to calculate an annual deep percolation amount. The upward flux from the water table that occurs between irrigation events will tend to offset the deep percolation from an individual event and the actual annual net deep percolation will be less. For this reason, the irrigation evaluations need to be just one part of a drainage reduction program which looks at the field on an annual basis and takes into account the upflux from the water table. Section III E of this report develops a procedure to calculate the annual net deep percolation.

C. SUBSURFACE DRAINAGE

1. Basic concepts

The goal of subsurface drainage is to maintain a sustained rootzone environment that does not inhibit maximum crop production. This normally means maintaining the salt balance and water table levels at appropriate levels.

A simple volume balance will indicate that if more water is being applied to a unit volume of soil than is being removed, the depth of water will rise. This is the case under irrigated conditions in parts of the Western San Joaquin Valley. As a result, subsurface drainage systems were required in these areas to remove the excess water and associated salts to maintain crop production.

In the study area there are two major types of drainage systems in use. These are deep open drains and subsurface tile drains. Figure 11 shows a three dimensional view of a typical field with examples of these type of drainage systems. This figure also shows some of the possible sources of water that may be contributing to the drainage problem. The most obvious sources are rainfall and deep percolation from irrigation. Rainfall is normally low in the valley. Deep percolation is that fraction of irrigation water that percolates below the crop rootzone and is not directly available to the crop. Other sources may be seepage from canals and farm laterals, lateral flow from other areas (fields), and upward flow from an underlying artesian aquifer.

Figure 11 shows three basic drain types. Drain 1 is an interceptor drain. Its purpose is to intercept or catch any water from an up slope source (up slope hydraulically and not necessarily topographically). As the figure shows, the drain is intercepting the canal seepage and prevents it from affecting the water table in the field.

Drain 2 is acting as a relief drain. Its major purpose is to

1. INTERCEPTOR / RELIEF DRAIN (SUBSURFACE TILE)
2. RELIEF DRAIN
3. OPEN DRAIN
4. WATER TABLE
5. CANAL SEEPAGE
6. ROOT ZONE
7. IRRIGATION

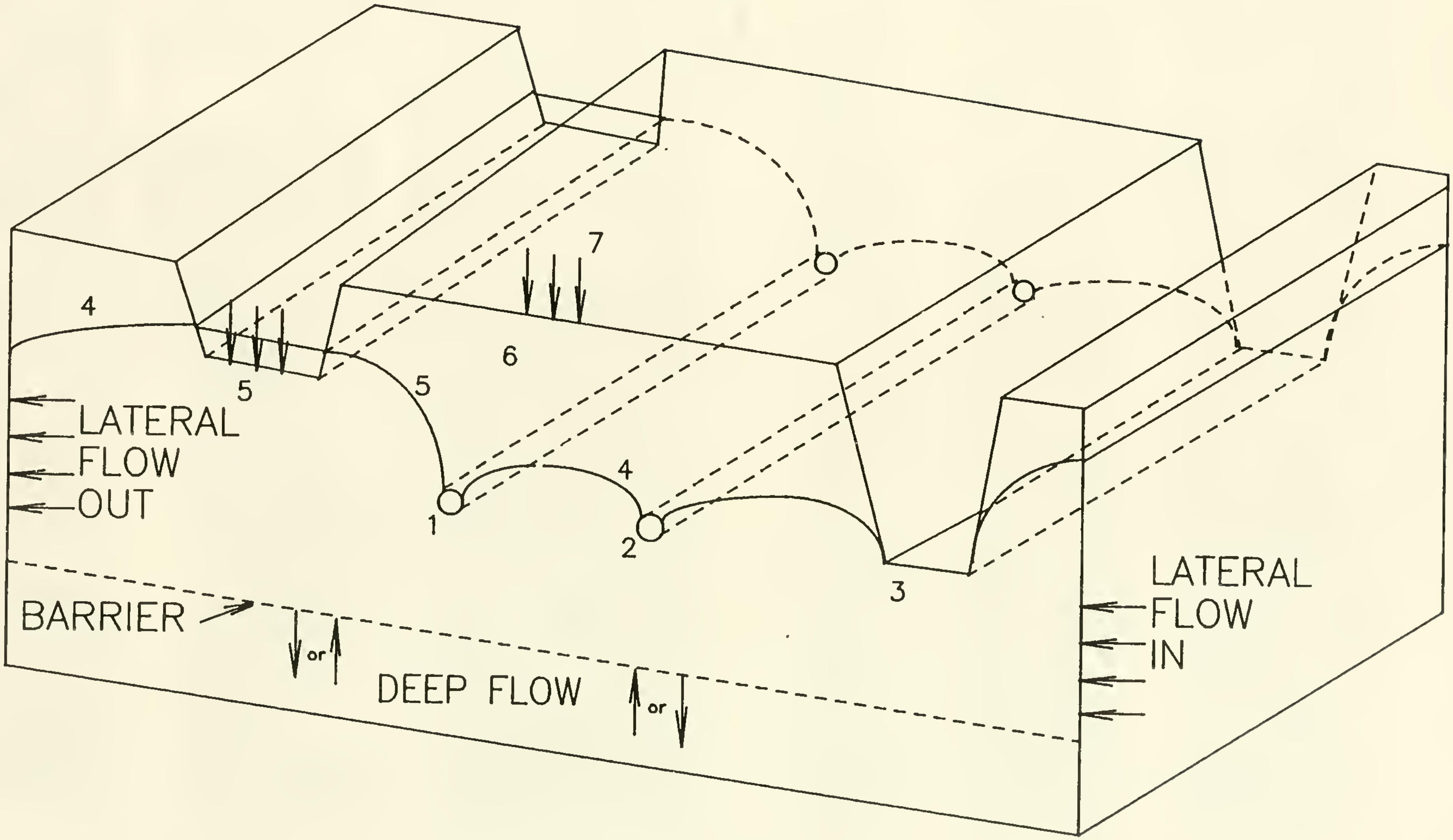


FIGURE 11 TYPICAL DRAINAGE SYSTEMS

drain deep percolation from irrigation. A properly designed drain may allow a gradual rise in the water table during the irrigation season, but will reduce the water table to the same height by the start of the next season. This is referred to as dynamic stability. In the study area, relief drains have a spacing that varies from about 100 to 600 feet. It should be noted that Drain 1 is acting as a relief drain as well as an interceptor drain.

Drain 3 is an open drain. It can act as a relief drain as well as an interceptor drain. In this case it is protecting the field from lateral water movement from outside the field boundary. This type of drain is not practical for relief drainage in cultivated areas where relatively closely spaced drains are needed, since the open trenches interfere with farming activities.

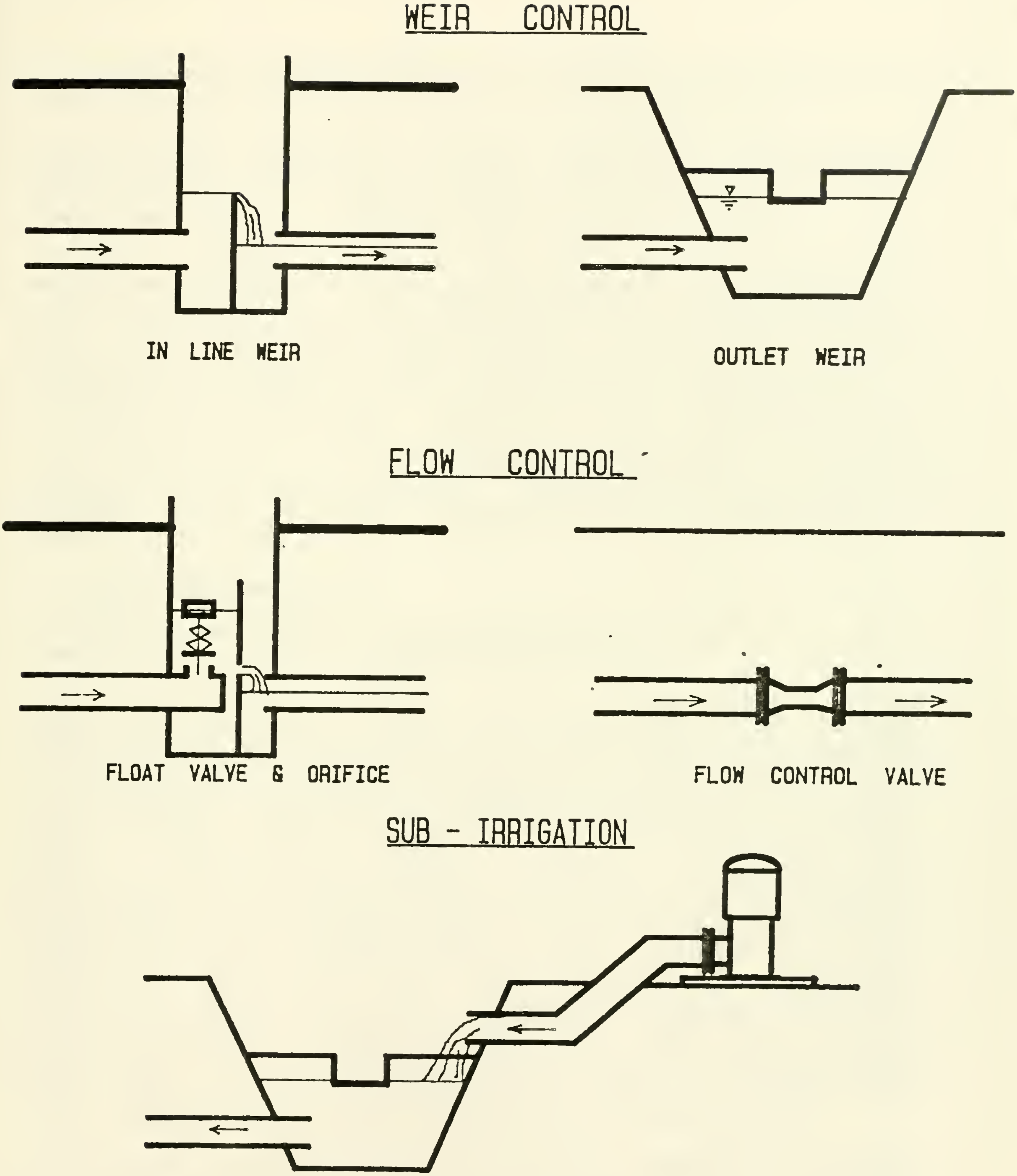
Once the water has entered the drain it must be removed. Ideally, this is done by gravity. In many cases this is not possible, so the drain water is diverted to a sump and then pumped into the removal facility.

2. Controlled drainage

One subsurface drainage practice which is more commonly done in humid regions is controlled drainage. This practice consists of installing some sort of water control gate or weir in-line on a subsurface drain or putting a weir to control the water level in an open drain into which a subsurface drain discharges. The weir or gate overflow elevation or orifice size can be set at different settings during different times of the year. The purpose of the control gate or weir is to decrease the discharge of subsurface drainage waters when it is desired to keep the water table at a higher level than under free drainage conditions and increase the water table contribution to crop ET.

Water table control techniques can be subdivided into three categories: weir control, flow control, and sub-irrigation. Weir control is done by putting a weir in the drain line or outlet ditch to raise the water level in the subsurface drain above its free discharge level. Drawings of two weir control schemes are shown in Figure 12. Weir control is the most common type of controlled drainage. With weir control, there is no control on the peak flows coming from the drains.

Flow control techniques are a new concept. What is controlled is not the water level in the subsurface drain but rather the peak flow which can come out of the drain. This can be accomplished by installing an orifice in-line with the drain line as shown in Figure 12. Flow control can also be done by installing drains that are smaller than what would be required to carry peak flow.



WEIR CONTROL

IN LINE WEIR

OUTLET WEIR

FLOW CONTROL

FLOAT VALVE & ORIFICE

FLOW CONTROL VALVE

SUB - IRRIGATION

FIGURE 12 TYPICAL SUBSURFACE DRAINAGE CONTROL METHODS

An in-line flow control valve which would work something like an irrigation flow controller could also be developed.

Sub-irrigation involves pumping irrigation water into the drainage system to supply the crop with water. Again, this is more commonly done in humid regions where salinity is not a concern and there are relatively narrow drain spacings.

Controlled drainage has not been widely practiced in the arid Western United States. Prior to the recognition of problems with sub-surface drainage constituents, there was little incentive to try it. The fact that increased crop use of a shallow saline water table can increase root zone salinization must be considered when applying controlled drainage in arid regions. If not practiced carefully, controlled drainage could reduce yields by increasing the salinity, boron, or other constituent in the root zone above the crop's tolerance level, or by bringing the water table up into the active root zone long enough to kill the roots due to a lack of oxygen. Controlled drainage therefore requires careful planning, implementation, and monitoring to assure its success.

3. Drainage system design

The various designers of subsurface drainage systems in the study area have used different approaches to design.

The SCS has designed many of the tile drainage systems in the study area, especially prior to 1975. The SCS has developed drainage guides for many areas around the United States, including the west side of the San Joaquin Valley. Field relief drains in arid regions are designed by the SCS using Houghoudt's steady state (ellipse) equation with inputs based on some field investigation and the guide book published for the region. The drain depth is determined by trying to place it in a permeable layer and by considering the economics involved. Drain spacing is determined by the Houghoudt's equation using the depth to barrier from field auger sites (usually on a 1000 foot grid), horizontal permeability from estimates based on soil texture in the auger sites, a minimum aerated root zone, and a drainage coefficient (inches of deep percolation to be drained per day between irrigations) from the region's guidebook. Tile drains are then sized to handle calculated peak flows based on the drainage coefficient. The SCS methods usually result in a conservative design which is not customized to a great extent for a given field. Some private consultants also use the SCS methods.

JMLord, Inc. has designed several drainage systems in the study area using methods in the United States Bureau of Reclamation's Drainage Handbook. Relief drains are based on what is commonly referred to as the Bureau of Reclamation, or, transient flow method. This is a non-steady state method developed by Glover-

Dumm for transient water table conditions. Drain depths are selected which put the drain in a permeable layer where possible and which results in the lowest drainage system cost to the farmer (this usually means as deep as the contractor's machine will go). A schedule of deep percolation amounts through the year is developed for each field based upon current irrigation practices. The horizontal permeability (hydraulic conductivity) is determined from auger hole "bail out" tests. The depth to barrier is determined by step auger hole "bail out" tests or by testing individual layers. An iterative process is then used to select a drain spacing which will keep the water table below a certain minimum aerated root zone depth and maintain dynamic equilibrium. The transient flow method uses the crop ET in these calculations. However, it does not consider the water table contribution to ET.

A large number of the drainage systems on the west side have been installed by local contractors based on a combination of economics (what the farmer can afford) and what has been done in nearby areas. A farmer may go to a contractor for a drainage system and the contractor may suggest a layout that seems to work in the given area and suggest a drain spacing of 500 feet. The client may then say he can not afford that system but can afford a 600 foot spacing. The contractor agrees and they try it out, with the possibility of having to go back in later and cut the spacing in half if it does not seem to be working.

One method which has been adopted by the SCS in humid regions is to use DRAINMOD, a computer model written by Skaggs (1978), to model the drain spacing and water table interaction. This model is based on Hooghoudt's steady state equation but uses small time increments. This enables modeling of transient water table conditions. This model does consider water table contribution to ET. DRAINMOD is discussed in more detail in later sections.

When drainage reduction is one of the design criteria, and especially where controlled drainage is to be used, a method which considers contribution of water table to ET should be used.

D. SALINITY CONTROL

1. Salt tolerance of crops

Crops vary in their tolerance to irrigation water and soil root zone salinity. Since the irrigation waters in the drainage study area are not injurious to any of the crops grown, the root zone soil salinity is the primary concern, unless subsurface drainage waters are being reapplied. A given crop under typical surface irrigation management will generally tolerate some amount of soil salinity (ECe) up to a certain threshold value without a decrease in yield. At levels above the threshold value, the yield will decrease proportionally with increased ECe. The most comprehen-

sive summary of crop salinity tolerance was done by Maas (1987). The salt tolerance values given are based on data developed where the crops were grown under conditions simulating recommended cultural and management practices for commercial production. In these studies, the ECe of the soil was kept constant throughout the depth of the root zone and constant throughout the growing season. In the drainage study area, soil profiles tend to increase in salinity with depth and the salinity changes through the year. Current evidence indicates that plant growth is most closely related to the soil-water salinity in that part of the root zone where maximum water uptake occurs. To accurately access the tolerance of a crop under field conditions, one would have to average salinity over time and determine the weighted average soil salinity based on the soil moisture extraction pattern. Because of the difficulty in doing this, standard practice is to use an average over time of the average salinity of the whole root zone. This probably results in a conservatively high estimate of yield reduction due to soil salinity.

Irrigation practices, frequency and amount applied, will affect the crop's response to salinity. Soil dryness stress, matric potential, and salinity stress, osmotic potential, felt by the crop are additive so that a crop's response to one cannot be considered without the other. The published tables can be used directly for typical surface irrigation management where the soil dries to typical management allowed depletions between irrigations. Crops will tolerate higher salinity levels than given in the table under high frequency irrigation, such as drip, where the soil is not allowed to dry between irrigations.

Other important factors which affect the tolerance of crops to salinity are the climate (temperature, humidity, air pollution), crop type and variety, and the fertility of the soils.

2. Specific ion toxicity

In addition to the general effect of salinity on crop yields, certain specific ions can be toxic to crops. This includes sodium, chloride, and boron. Most annual crops are not sensitive to sodium and chloride, but boron is a major concern in the drainage study area. Certain trace elements such as molybdenum and selenium may also be of concern for their effects on the health of the plants themselves or to the consumer of the plants.

Crops vary in their tolerance to boron. Maas (1987) also show the most complete listing of crop boron tolerance data. Maas presents only a threshold range of values where reductions in yield occur is given for each crop. A range is given because boron tolerance also varies with climate, soil conditions, and crop variety. Maas also states that yield reductions as a function of boron concentration generally cannot be predicted from available data. The Agricultural Water Management Subcom-

mittee to the San Joaquin Valley Drainage Program did, however, include a figure in its 1987 report which shows yield reduction versus boron concentration.

3. Leaching and salt balance

When salts or boron have built up in a soil to levels that will reduce yields, applications of water for leaching are required. When soils have become sodic, that is high in sodium versus calcium plus magnesium, soil amendments such as sulfuric acid, calcium chloride, or gypsum need to be applied prior to leaching. The amount of leaching water needed to lower the salinity or boron concentration of the soil is highly dependant on the soil characteristics and the method used to apply the water. Hoffman (1980) summarized many field leaching trials in three diagrams. One is for leaching of salts using intermittent ponding, one is for leaching of salts with continuous ponding, and one is for leaching of boron with either intermittent or continuous ponding.

Once the soil has been sufficiently reclaimed so that soil salinity and boron concentrations will not reduce crop yields, applications of water in excess of ET are needed to maintain the salt and boron balance of the soil, since the irrigation water continuously brings in new salts and Boron. The minimum amount of water that must pass below the root zone to maintain salt and boron balance without injury to the crop is called the leaching requirement. The leaching requirement depends primarily upon the salinity and boron content of the applied water and the tolerance of the crop. Leaching to meet the leaching requirement can be applied continuously or at intermittent intervals ranging from months to years. The temporary build up in root zone salinity or boron content between leaching applications will increase as the interval increases and must be considered in irrigation and drainage management.

Calculating a leaching requirement for a given set of circumstances is an inexact procedure as this aspect of irrigation is still not fully understood by irrigation experts. There are many external factors affecting it. These factors include the irrigation practices (intervals, amounts applied, irrigation type), soil characteristics, water and soil chemistry, and crop.

Many equations and models have been advanced for calculating a leaching requirement based on EC. Hoffman (1985) compared five steady state models which are the most frequently used. None of the models were completely satisfactory, as there was considerable scatter between experimentally measured values and the predicted values for leaching requirement. A model, based upon an exponential pattern of crop water uptake, correlated best with the measured values but underestimated the leaching requirement at higher levels of leaching requirement. A graphical solution of that model is shown as Figure 13.

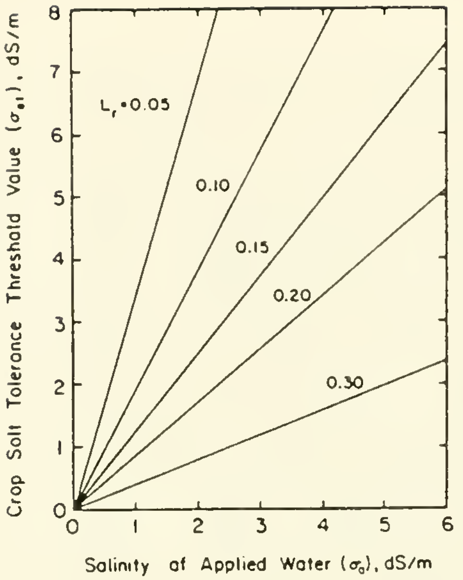


Figure 13. Graphic Solution of the Exponential Model for Leaching Requirement. Source: Hoffman (1985)

An example calculation for this method is as follows:

EC of the irrigation water is 0.5 dS/M
Crop is tomatoes (salinity threshold = 2.5 dS/M from Maas)
From the graph, leaching requirement is approx. 0.035 or 3.5%
Tomato ET is 28 inches from DWR (1974)
Total leaching water is 28 x 0.035 = 1.0 inch

It is important to recognize that the leaching requirement assumes that the distribution uniformity is 100 %. Since this is never true in field conditions, the lack of uniformity must be considered in addition to the leaching requirement when calculating the minimum amount of deep percolation that can be allowed in a field without a buildup in soil salinity. A means for doing this is discussed later.

Since the determination and field application of leaching fraction are difficult, it is a common practice to apply a leaching fraction conservatively above the calculated leaching requirement to avoid salinization of the root zone.

E. DISTRIBUTION UNIFORMITY AND LEACHING REQUIREMENTS SET LIMITS TO FLOW REDUCTION

If subsurface drainage flows are reduced below a certain limit, portions of the field will no longer have an annual salt balance and will begin to have a long term increase in salinity. Figures

14 and 15 illustrate what should be the governing criteria for designing and managing a drainage flow reduction program.

Figure 14 first shows a water destination graph which represents the amount of water which infiltrated into the soil during the first irrigation plus rain over the field area (assume 100% uniformity for rainfall or a sprinkler pre-irrigation). The soil moisture deficit is a result of the ET and upflux from the water table which has occurred since the last irrigation. The second sketch represents the ET which occurs between the first and second irrigations. The third sketch shows the upflux into the root zone from the water table that occurs between the first and second irrigations. Note that this is not necessarily the same magnitude across the field. The fourth sketch shows the water destination graph from the second irrigation. The soil moisture depletion at the time of the second irrigation is equal to the ET that has occurred since the first irrigation minus the upflux that has occurred since the first irrigation. Each succeeding irrigation then follows the same process.

An annual water destination graph (Figure 15) can be produced by adding all of the irrigation applications together. A line is drawn for the total ET for the year. The shaded area which falls below the ET line represents the net deep percolation (NDP). The NDP consists of two components: that amount which is due to over-irrigation of the minimum point, and that amount which is due to lack of distribution uniformity. The following two equations can be written:

$$\mathrm{NDP} = \mathrm{AAI} + \mathrm{RF} - \mathrm{ET}$$

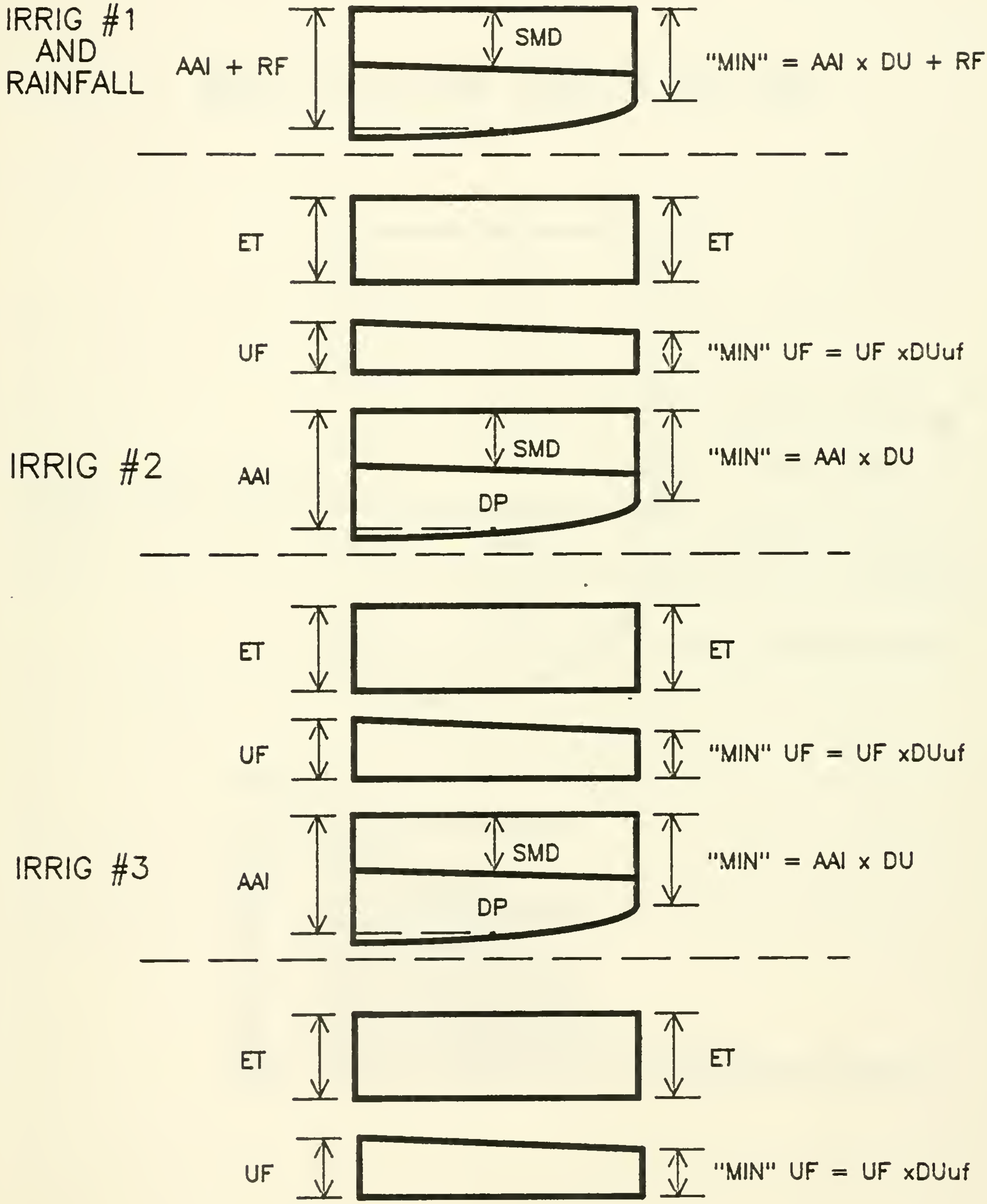
$$\mathrm{NDPoi} = (\mathrm{AAI} \times \mathrm{DUa}) + \mathrm{RF} - \mathrm{ET}$$

Where NDP = Net Annual Deep Percolation
NDPoi = Net Annual Deep Percolation due to over irrigation
AAI = Sum of the Avg. Amt. Infilt.
RF = Annual Infiltrated Rainfall
ET = Annual Evapotranspiration
DUa = Annual Distribution Uniformity

These equations can be combined and rearranged for the condition when the NDP is the minimum possible. This occurs when the NDP due to over irrigation equals the annual leaching requirement.

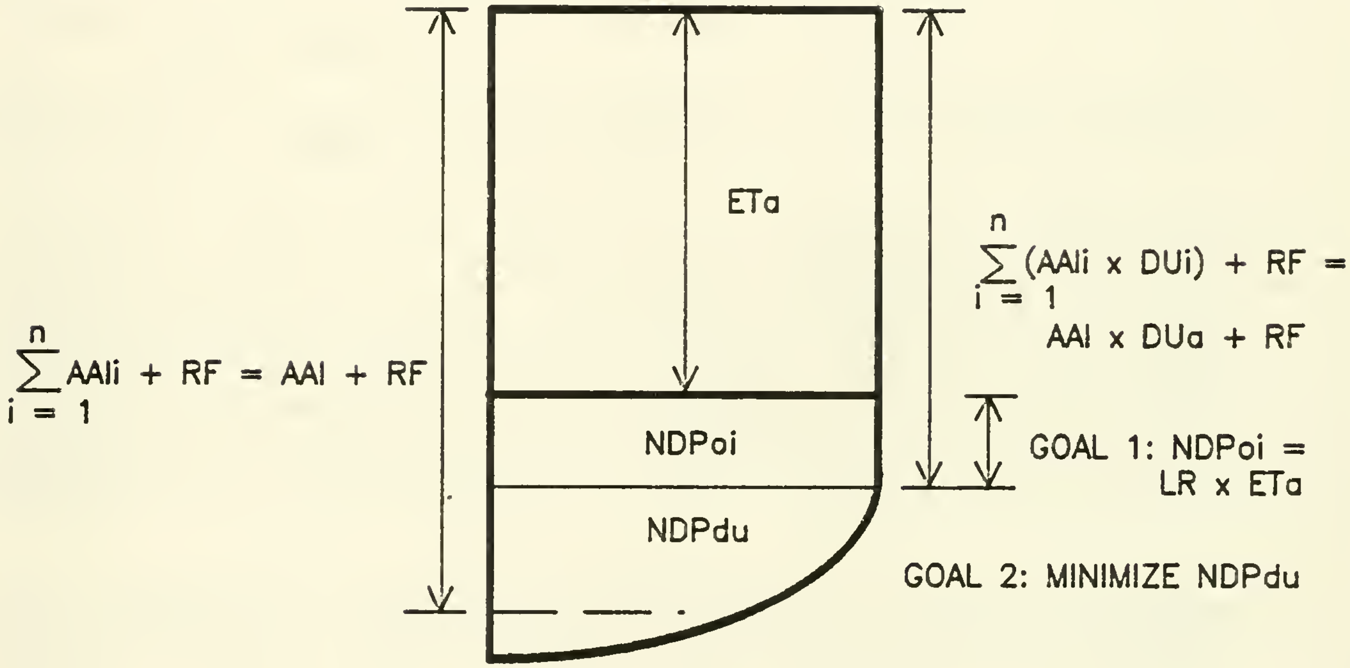
$$\mathrm{NDPmin} = \mathrm{ET}((1+\mathrm{LR})/\mathrm{DUa} - 1) + \mathrm{RF}(1-(1/\mathrm{DUa}))$$

FIGURE 14 Water Destination Graphs for Individual Events



(see definitions on the next page)

FIGURE 15 Water Destination Graph for Full Year



Definitions:

AAI = Average Amount Infiltrated
RF = Rainfall
SMD = Soil Moisture Deficit
DP = Deep Percolation
MIN = Minimum Amount Infiltrated
DU = Distrigution Uniformity
ET = Evapotranspiration
UF = Upflux from Water Table
ETa = Annual Evapotranspiration
DUa = Annual Distribution Uniformity
LR = Leaching Requirement (%)
NDPoi = Net Deep Percolation due to Over-Irrigation
NDPdu = Net Deep Percolation due to Lack of Distribution Uniformity

To illustrate how the leaching requirement and the annual distribution uniformity are used to set the limiting NDP, the following example is given:

Crop is tomatoes
Leaching requirement is 3.5% (from previous example).
Annual ET is 28 inches
Annual Rain is 6 inches
Annual Distribution Uniformity = 75%

$$\begin{aligned} \mathrm{NDPmin} &= (28*(1.035/0.75 - 1) + 6*(1 - (1/0.75)) \\ &= 8.6 \text{ inches} \end{aligned}$$

Note that the distribution uniformity of the upflux does not enter into the calculation directly.

If the annual distribution uniformity in the above example were improved to 85%, the limiting net deep percolation would be reduced to 5.0 inches. This shows how important DU is in a drainage reduction program. The leaching requirement is determined by the crop and the irrigation water quality as discussed above and is not something that can be managed. Distribution uniformity is something which can be managed to a certain extent. Obtaining high distribution uniformities therefore becomes very important in the management of the drainage flow reduction program.

Temporary salinity or boron buildups in the root zone during the season could still occur with the drainage flow reduction program outlined above. This becomes especially crucial if the soil chemistry is right on the border line of causing yield reductions to begin the year. Ideally, a salinity model would be desirable to be able to predict problems before they occur. Dr. Andrew Chang of U.C. Riverside has been working on a salinity model to incorporate into DRAINMOD. However, a modification to the program may first be required to make it work because of the way the program models moisture extraction from the root zone. For now, this problem has to be avoided by ensuring that the soil chemistry is not on the border line to start the season, by spreading out the leaching applications where possible, and by monitoring the soil throughout the season.

IV. INTEGRATED SUBSURFACE DRAINAGE FLOW REDUCTION SCHEME

A. DRAINMOD - A TOOL TO INTEGRATE IRRIGATION AND DRAINAGE CONCEPTS

For fields without a shallow water table, SWAP/ET has been a good tool, along with system evaluations, for managing irrigation events. This is in part because each event can be viewed as independent of the other irrigation events. However, on fields with a shallow water table, the management of each event is very much dependent on every other irrigation event. What has been needed is a tool to incorporate the results of the SWAP/ET program, the irrigation system evaluations, the water table fluctuations and the irrigation events into an integrated system. DRAINMOD is a water balance model that offers that possibility.

DRAINMOD is a computer model that was designed to predict the seasonal variations in the water table and the influence of the water table on crop water use (Skaggs, 1980). In order to develop a water balance, DRAINMOD uses the following primary inputs:

(1) Crop water use - Evapotranspiration data can be either calculated from input maximum and minimum daily temperatures using the Thornthwaite method, or, from ET data calculated from other methods, such as SWAP/ET.

(2) Rainfall and irrigation - This data is input on an hourly basis.

(3) Infiltration - The model requires parameters for the Green-Ampt infiltration equation.

(4) Subsurface drainage - The configuration of the subsurface drainage system is required. This includes the drain spacing, depth, capacity, weir setting vs. time, and effective tile radius.

(5) Crop - If potential ET is an input, then monthly crop use factors are required. Also required is a time-depth relationship for the crop root zone.

(6) Soils - Inputs required include;
Moisture release curve
Air volume vs. water table depth (WTD)
Upward flux potential vs. WTD
Lateral and vertical saturated hydraulic conductivity vs. soil layer
Depth for each layer to the barrier

This model was developed for the humid conditions of the eastern U.S., and therefore has not been fully tested for arid irrigated agricultural in the western U.S. At least one attempt has been made by Chang, et.al., in 1983. This effort was based on data

from a report of conditions for a range of drained fields throughout the San Joaquin Valley (Pillsbury and Johnston, 1965). The conclusions of that research effort are quoted as follows:

> (1) Based on these results, DRAINMOD can simulate the water balance in an irrigated cropland, Water table elevations predicted by DRAINMOD agreed reasonably well with measurements for five experimental locations differing in soil texture in the San Joaquin and Imperial Valley's of California.
>
> (2) Water loss by deep seepage is a significant component in soil water balance for the irrigated croplands tested.
>
> (3) When the water table drawdown exceeded 150 cm, the model tended to overestimate the depth of the water table.

There are two important factors that the current version of the model does not estimate. They are the deep water movement, either upward or downward across the barrier, and salt movement associated with water movement. Chang, et.al. (1983), have attempted to incorporate the loss of water through deep seepage based on some simplifying assumptions about the barrier. Chang (personal communication) has also attempted to modify the program to account for salt movement. These subroutines will be evaluated for inclusion in the future use of DRAINMOD for this project. Another factor in the success of the proposed systems of water management is the distribution uniformity (DU) of irrigations. Although not addressed directly with the DRAINMOD-SWAP/ET program, the method of estimating and utilizing DU is discussed elsewhere in this report. While acknowledging some possible limitations of DRAINMOD, it is stressed that this is the only known existing platform from which to begin the process of integrating the required elements of a successful water management program on water table affected fields.

B. INTEGRATED APPROACH TO SUBSURFACE DRAINAGE REDUCTION

1. Irrigation scheduling

The scheduling of irrigations will be one component of the drainage reduction plan. Changing irrigation dates will affect the amount of deep percolation during the irrigation, and will also affect the contribution to ET from the water table. DRAINMOD and SWAP/ET will be used together to schedule irrigations. For cotton, measurements of leaf water potential with a pressure chamber will be used to make sure that the crop is not stressed. SWAP/ET will be used to determine historical and current ET data for use by DRAINMOD. DRAINMOD will be used to perform a daily water balance over the soil root zone and water

table.

Although soils do not dry as modeled by DRAINMOD, the overall root zone average should be an approximation of current soil moisture depletion. Since DRAINMOD does not consider salinity, the management allowable depletion (MAD) factor will be modified to account for salinity as necessary based on laboratory analysis.

A list of the data required for DRAINMOD-SWAP/ET system is as follows:

- SWAP/ET
  - Climatic data (daily) including;
    - Temperatures
    - Maximum
    - Minimum
    - Dew point
    - Solar radiation
    - Wind run
  - Crop
    - Growth curve
    - Planting date
    - Cover date
    - Irrigation cut-off date or defoliation date

- DRAINMOD
  - ET (daily evapotranspiration from SWAP/ET)
  - Rainfall (hourly)
  - Irrigations (input as rainfall)
  - Soils (for each layer)
    - Depth
    - Lateral saturated hydraulic conductivity
    - Vertical saturated hydraulic conductivity
    - Soil moisture release curve
    - Depth to barrier
    - Water table depth at beginning of simulation
    - Infiltration parameters (Green-Ampt or other)
  - Drainage system
    - Drain spacing
    - Drain depth
    - Weir depth (monthly by day of setting)
    - Effective radius of drain line
  - Crop
    - Root zone growth curve
    - Wilting point soil moisture
    - Dates between which the hours are accumulated when the water table is within a selected depth of the surface

2. Irrigation system evaluation and design

Irrigation evaluations are also an important component of the drainage flow reduction scheme. Reducing the deep percolation from an irrigation event will affect the buildup in the shallow water table and the flow in the subsurface drains. Increasing the distribution uniformity will also affect the ultimate limit to the drainage flow reduction which is possible.

3. Drainage effluent flow control

a. Weir control schemes

The use of weirs to control the water table will be an adaptation of controlled drainage, subsurface irrigation systems technology. The intended outcome from using the weir will be to keep the water table closer to the root zone during the growing season, while allowing the required quantity of water for leaching to drain out at selected times of the year.

The structural part of this system will be based on the DOS IR control valve, as manufactured by Fiberglass Utility Supplies, Inc. This valve is made to be installed in-line with drain lines. It is constructed so that a weir plate can be adjusted within a range of levels from the bottom of the structure. At the bottom is a second plate that can be opened to allow free flow of the drain water.

The most probable use of the weir control scheme will be to leave the lower door open for a portion of the year, possibly from post harvest to planting time, in order to allow the required leaching water to drain out. The remainder of the year, the lower door will be closed and the weir will be set in position. The depth of this setting will be such that the water table will not rise up into the root zone while holding back the water that would otherwise drain out through the system.

b. Flow control schemes

Whereas the weir scheme will release water at an uncontrolled rate when it spills over the weir or when the bottom gate is opened, the flow control scheme will be intended to release water up to a maximum flow rate. The designed maximum flow rate will be based on DRAINMOD simulations.

In order to have a regulated maximum flow, an orifice plate could be placed in-line with a float valve as shown in Figure 12. The DOS-IR valve could be used without a weir plate. Instead, the bottom gate that can be opened for free flow will have an orifice cut into it. The design of the DOS-IR valve is such that should it be necessary to change the orifice size during the growing season, it will be possible to pull out the gate and replace it

with a gate having a different orifice.

c. Shallow drains

As mentioned previously, one way to reduce drain outflows is to control the depth of the water table closer to the bottom of the crop root zone and make more of the water table available for contribution to ET. Shallower drains would result in smaller fluctuations of water table heights between drains than would occur under a deep drainage network and thus keep the water table closer to the root zone and more available for crop water use. Shallow drains are, however, usually more costly than deep drains because a narrower drain spacing is required to maintain the same maximum water table elevation at the mid point between drains.

d. Drain spacing

When designing a new system, the option of using wider spaced drains than other design methods would suggest can be looked at with DRAINMOD. The wider spaced drains will tend to allow more water table contribution to ET and thus less drain flow because the water table will reach dynamic equilibrium at a higher level.

C. PRACTICAL APPLICATIONS OF DRAINMOD-SWAP/ET

1. New drainage system design

New drainage systems can be designed by DRAINMOD-SWAP/ET incorporating drainage flow reduction as one of the design criteria. A year or more of historical weather data can be run through SWAP/ET to calculate ETp and crop ET. This is then fed into DRAINMOD with rainfall, irrigations, soils data and the other necessary inputs. The drain spacing, placement depth, pipe size, and optionally a weir setting can all be designed by trying various options and selecting the one which best fits the design criteria. To the best of the authors' knowledge, this is the only way at the present time to incorporate flow reduction including controlled drainage into drainage system design.

2. Design of modifications for existing drainage systems

A similar process can be used with DRAINMOD-SWAP/ET to design modifications to existing drainage systems. The main difference is that the drain spacing, pipe size and placement depth is already fixed. Weir control, flow control, and irrigation management become the parameters which can be varied to select the best option to meet the design criteria. It would also be possible to investigate adding new drains, but only on a constant spacing and set at the same depth as the original drains with the current version of DRAINMOD.

3. Planning a management strategy at the beginning of the crop season

A management strategy can be mapped out prior to a season by using DRAINMOD with historical ET fed from SWAP/ET. Options to look at are how much to apply during the different irrigations, when to irrigate, and what weir settings or flow control settings to use.

4. Week to week irrigation scheduling

As the actual weather data and field monitoring data come in, new runs of DRAINMOD-SWAP/ET can be made to update the forecast of the next irrigation date and amount. Calibration of the model would be done if monitoring of the soil moisture and water table show differences from the model predictions. A good time to do the simulation would be following each irrigation.

5. Modeling of what actually happened

When a season is over, the actual field data can be used to make modifications to DRAINMOD-SWAP/ET to increase its accuracy for future use in that field and other similar fields.

D. SAMPLE RUNS THROUGH DRAINMOD-SWAP/ET

In order to test the DRAINMOD-SWAP/ET model, a number of possible scenarios were run. The purpose of these runs was to become familiar with the model and to look for any trends in water management that result from the different scenarios. The inputs for these runs were developed from a variety of sources. As noted in Chang, et al. (1983), there is no single source with a complete data set for the needs of DRAINMOD-SWAP/ET. Therefore, no attempt was made to evaluate the model for a specific situation. Rather, a set of data was gathered that might represent a "typical" field in the study area. Each run was for a calendar year. The sample runs made were as follows:

"A" Uncontrolled drain flow with no irrigation scheduling or system evaluations (UNCONTROLLED DRAINAGE/NO MANAGEMENT), with a 400 ft drain spacing at a depth of 7.4 ft.
"B" UNCONTROLLED DRAINAGE/WITH MANAGEMENT (400' by 7.4')
"C" UNCONTROLLED-SHALLOW DRAINAGE W/MANAGEMENT (400' by 5.5')
"D" UNCONTROLLED DRAINAGE/WITH MANAGEMENT (600' by 7.4')
"E" WEIR CONTROLLED DRAINAGE W/MANAGEMENT (400' by 7.4')
"F" FLOW CONTROLLED DRAINAGE W/MANAGEMENT (400' by 7.4')

1. Inputs for Sample Runs

(1) Crop water use - Weather data for the 1987 cropping year was gathered from the Telles CIMIS weather

station. This data was input to SWAP/ET, along with a JMLord cotton crop curve, to develop the daily ETp and ET (Figure 16).

(2) Rainfall and Irrigation - The Telles CIMIS rainfall data was not considered to be reliable because of the influence of sprinklers. Therefore, daily rainfall measured by a ranch east of Firebaugh was used.

For run "A", the irrigation dates and amounts were taken from irrigation delivery records for a single cotton field in Broadview Water District. For all of the remaining runs, the seasonal irrigation dates and amounts were selected to achieve the following objectives:

For the managed runs, an irrigation event was triggered when the average root zone soil moisture depletion was between 45 and 50 per cent, with the over-riding consideration that the depletion at defoliation, September 15, should be between 60 and 65 per cent of the available moisture.

DRAINMOD assumes a soil moisture that is not depleted at the beginning of the trial run. In order to simulate a static situation from year to year, the irrigation events were scheduled to achieve this condition at the end of the year.

The preseason irrigation date was left the same for all runs. The amount of this irrigation will be discussed with the results of the trial runs.

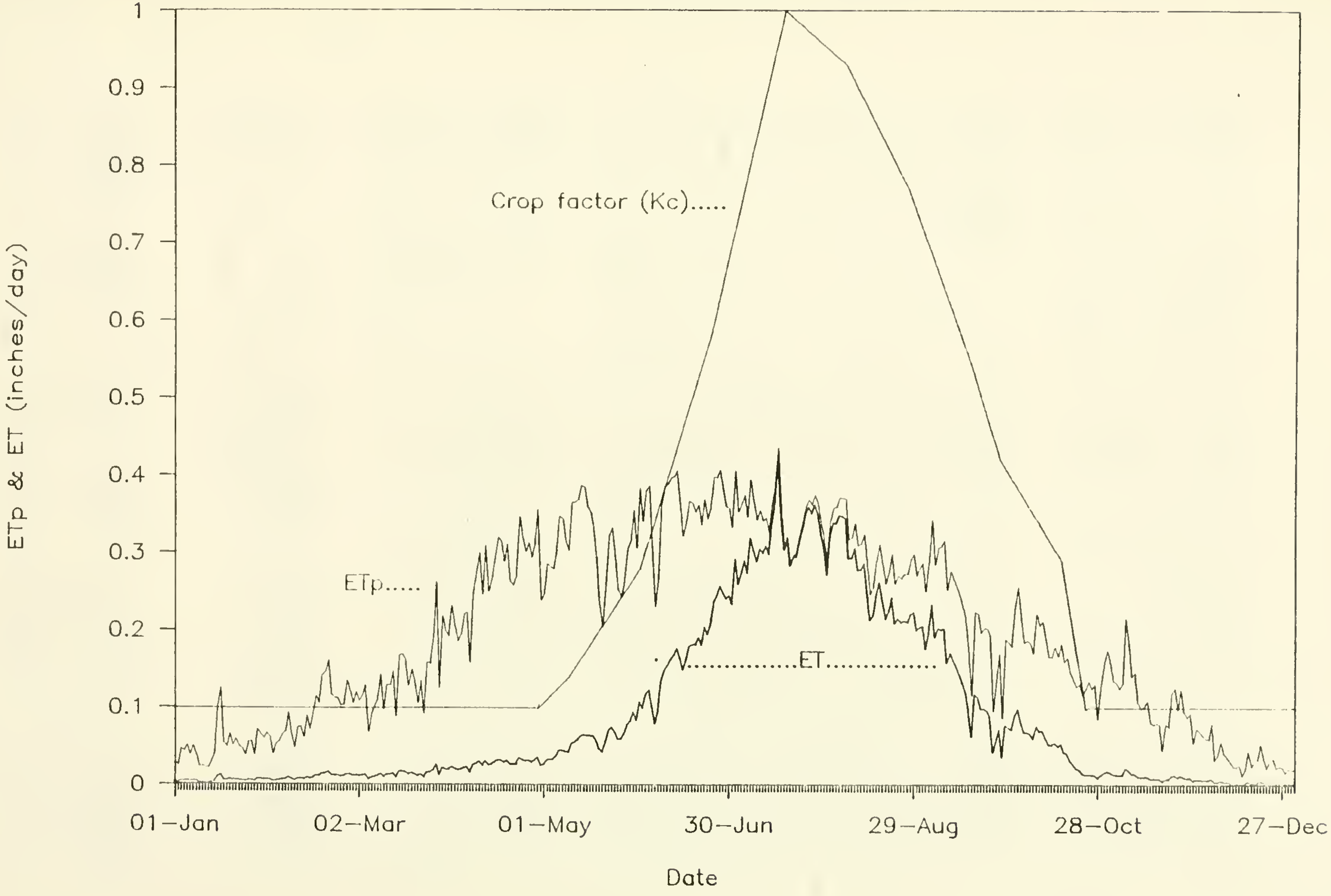
(3) Infiltration - For these trial runs, the average amount of irrigation water that infiltrated into the soil was used for irrigation amounts rather than the gross applied. The parameters for the Green-Ampt calculation were adjusted to allow all of the irrigation water to enter into the soil.

(4) Subsurface drainage - The drain depth and spacing for each run are as indicated in the above run descriptions. The other primary system factors are:

Drainage coefficient - This is a factor that reflects the flow capacity of the drainage system, expressed in cm/day. For all of the runs except "F" (Flow control), the factor used was based on the capacity of a corrugated plastic four inch drain line on a 0.001 ft/ft slope that is 1320 feet in

FIGURE 16 COTTON Kc, ETp, & ET

Telles Ranch Weather Data, 1986–87



length. This was a factor of 0.26 cm/day for all of the trials except the 600 ft spacing. That trial had a coefficient of 0.17 cm/day. For trial run "F", the coefficient was reduced to 0.10 cm/day. The purpose of this reduction was to simulate a flow control restriction to drain flow, and to see what the relative effect would be on drain flow and the water table level.

Weir setting - For a controlled drainage situation in DRAINMOD, it is possible to set the level of a weir. This weir is assumed to be at the outlet of a drain ditch that receives drain line water as well as surface runoff. In conjunction with the weir setting, the dimensions of the drain ditch are input for storage volume calculations. With this system, there can be portions of a year when the water in the ditch will run back into the drain lines, effectively a subsurface irrigation condition. Since the drain systems in the study area are not all set up with drain ditches, the drain ditch dimensions were set very small. The weir was set at 140 cm below the soil surface from just prior to the preseason irrigation, Nov. 1, to near the beginning of the growing season, May 31. It was set to 170 cm for the month of June, to 200 cm from July 1 to Aug. 31, and to 230 cm for the months of Sept. and Oct.

Water table - DRAINMOD predicts the depth of the water table at the mid point between drains throughout the year. The current version of DRAINMOD allows only one water table depth to be entered, the starting depth. For the trial runs, the starting depth was adjusted so that the water table level was approximately the same at the end as at the start of the simulated year.

(5) Crop - The crop used for these simulations was cotton. The root zone growth curve was established based on a root growth function (Borg and Grimes, 1986) with a maximum depth of 160 cm and a growing season length of 180 days.

(6) Soils -

Depth of each layer and the respective moisture release curve - This data was based on Grimes et.al., 1984. The soil used was a Panoche loam. From the Telles Ranch in the drainage study area. From the soil characteristics reported, it was decided to assume a two layered soil to the barrier.

The shallow layer was from the surface to 183 cm with the second layer extending to the barrier at an assumed depth of 610 cm. The moisture release curve used was an average of the values reported for each potential. The average available moisture, between 1/3 and 15 bars, was 0.2 cm/cm.

Air volume vs. water table depth - Supplied with the DRAINMOD program, there is a set of companion programs for preparing inputs to the main program. One of these programs is WTVOLDRN, which is a program "...to prepare a volume drained versus water table depth table from the soil water characteristic curves of each layer of the soil".

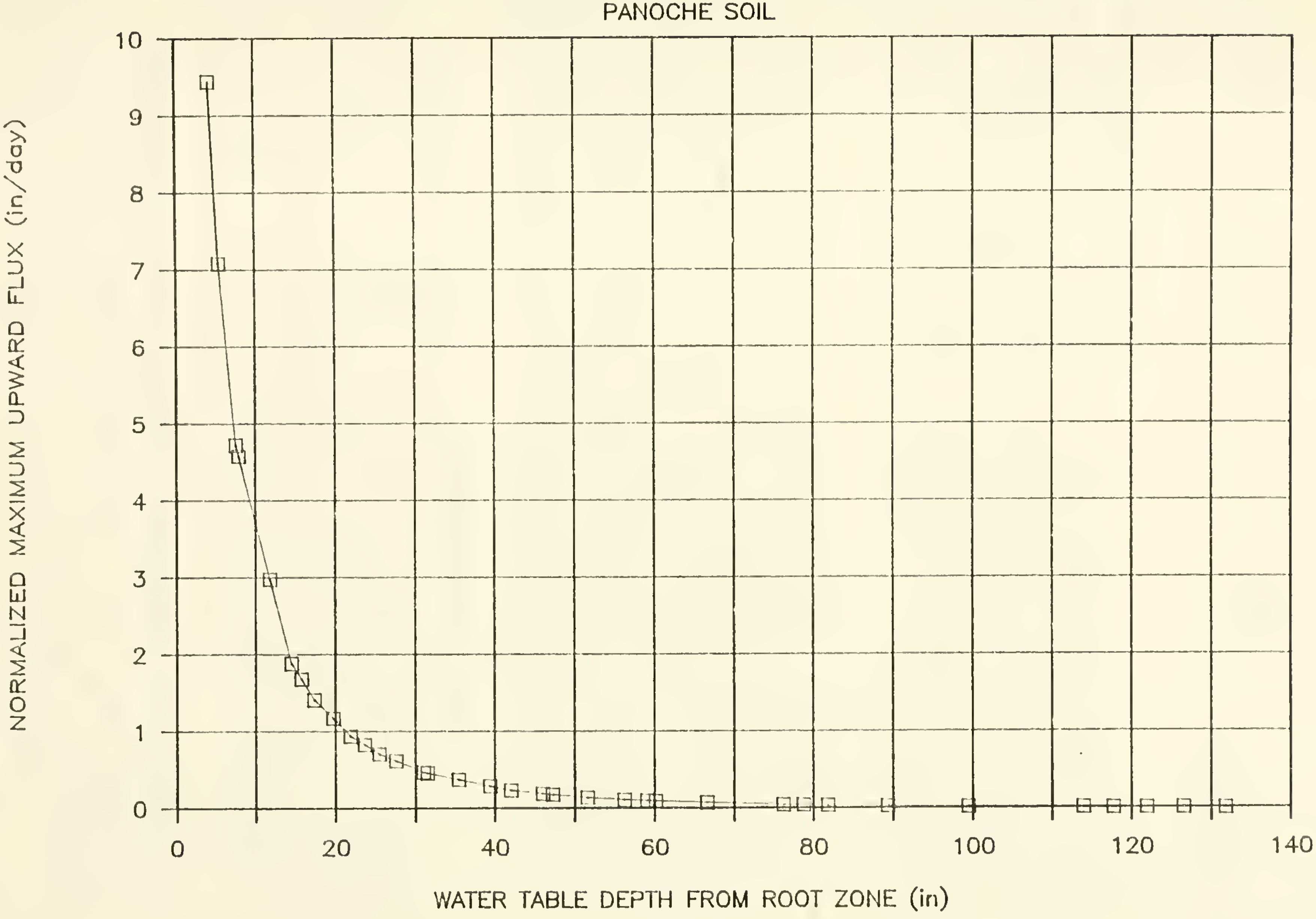
Vertical saturated and unsaturated hydraulic conductivity - Another of the companion programs is MILNQRK. This is a program to "...approximate the unsaturated conductivity of each layer of the soil using the soil water characteristic and saturated vertical conductivity. The method used is from Millington and Quirk." The saturated vertical conductivity can be estimated based on the lateral saturated conductivity. The authors of this program suggest that the vertical conductivity be estimated as 1/2 to 1/4 of the lateral conductivity. For the purposes of these trial runs, the vertical were estimated as 1/10 of the lateral conductivities, based upon JMLord, Inc.'s drainage design experience in the area.

Upward flux potential vs. water table depth (WTD)- The third of the companion programs is UPFLUX. This is a program "...to calculate the steady state upward flux versus water table depth curve from the unsaturated conductivity function of each soil layer." The results for these runs are shown in Figure 17.

Lateral saturated hydraulic conductivity vs. soil layer - The lateral saturated conductivity can be determined in the field using techniques such as the "bail-out" test. For these trial runs, the soil layers were assumed to have conductivities of 3.3 and 11.4 cm/hr, in the upper and lower layers respectively, based on the results from previous conductivity tests in the area.

As an effort to simplify the soils data inputs to DRAINMOD, the SCS's National Soil Survey Laboratory, in Lincoln, Nebraska, is attempting to develop a series of computer programs to produce these inputs (Baumer, personal communication). The basis of

FIGURE 17. UPFLUX vs. WATER TABLE DEPTH



PANOCHE SOIL

these efforts is a large data base of soils data.

Appendix A is a sample printout of the inputs for a DRAINMOD-SWAP/ET run.

2. Results of the trial runs

The results of the trial runs are summarized in Table 5 and Figures 18 through 23. Figures 18 through 23 show the daily changes in water table and root zone depths, as well as the drain line and irrigation depths. The numbers shown as percents are the average depletion of the available root zone soil moisture the day before each irrigation and at the time of defoliation. Figure 30 shows the monthly drain flows, in cm per unit of field area, for each trial run. In the discussion of each trial run's results, any comparisons made are to trial run "A".

a. UNCONTROLLED DRAINAGE/NO MANAGEMENT ("A") trial run

Figure 18 shows the results of this trial run. The irrigation events occurred when the soil moisture depletion was 43, 36, 43, 35, and 34 percent. The total of the irrigation plus rainfall was 41.9 in. (rainfall was 6.8 in.) with 1.1 in. of runoff after the preseason irrigation. Of the amount infiltrated, 71.3 went to evapotranspiration and 13.1 in. left the field through the drain. The average leaching fraction was 32.2%. This was the only trial run with surface runoff. Runoff occurred when the pre-irrigation brought the water table to the ground surface and no more water would go into the soil. This occurred because the soil moisture depletion at defoliation was only 34% of the AWHC.

b. UNCONTROLLED DRAINAGE WITH MANAGEMENT ("B") trial run

Figure 19 shows the results of this trial run. The effect of management was to reduce the total of the irrigation plus rainfall by 6.0 in. to 35.8 in. and the drainage by 5.5 in. to 7.6 in. The contribution of upflux to ET was reduced to 1.7 in. from 2.6 in., primarily because of a general lowering of the water table. The irrigations were scheduled at depletions of 45, 40, and 31 percent with a 62 percent depletion at defoliation. The late season irrigation at a 31 percent depletion was necessary to meet the target depletion at defoliation.

c. UNCONTROLLED-SHALLOW DRAINAGE W/MANAGEMENT ("C") trial run

Figure 20 shows the results of this trial run. The effect of having management along with designing the drains for a shallower depth, 5.5 vs. 7.4 ft., was to decrease the rainfall plus irrigation by 9.0 in. to 32.8 in. and the drainage by 8.6 in. to 4.5 in. The leaching fraction was reduced to 13.8 percent.

FIG. 18. UNCONTROLLED DRAINAGE/NO MAN.

DRAINMOD-SWAP/ET RUN FOR SJVDP

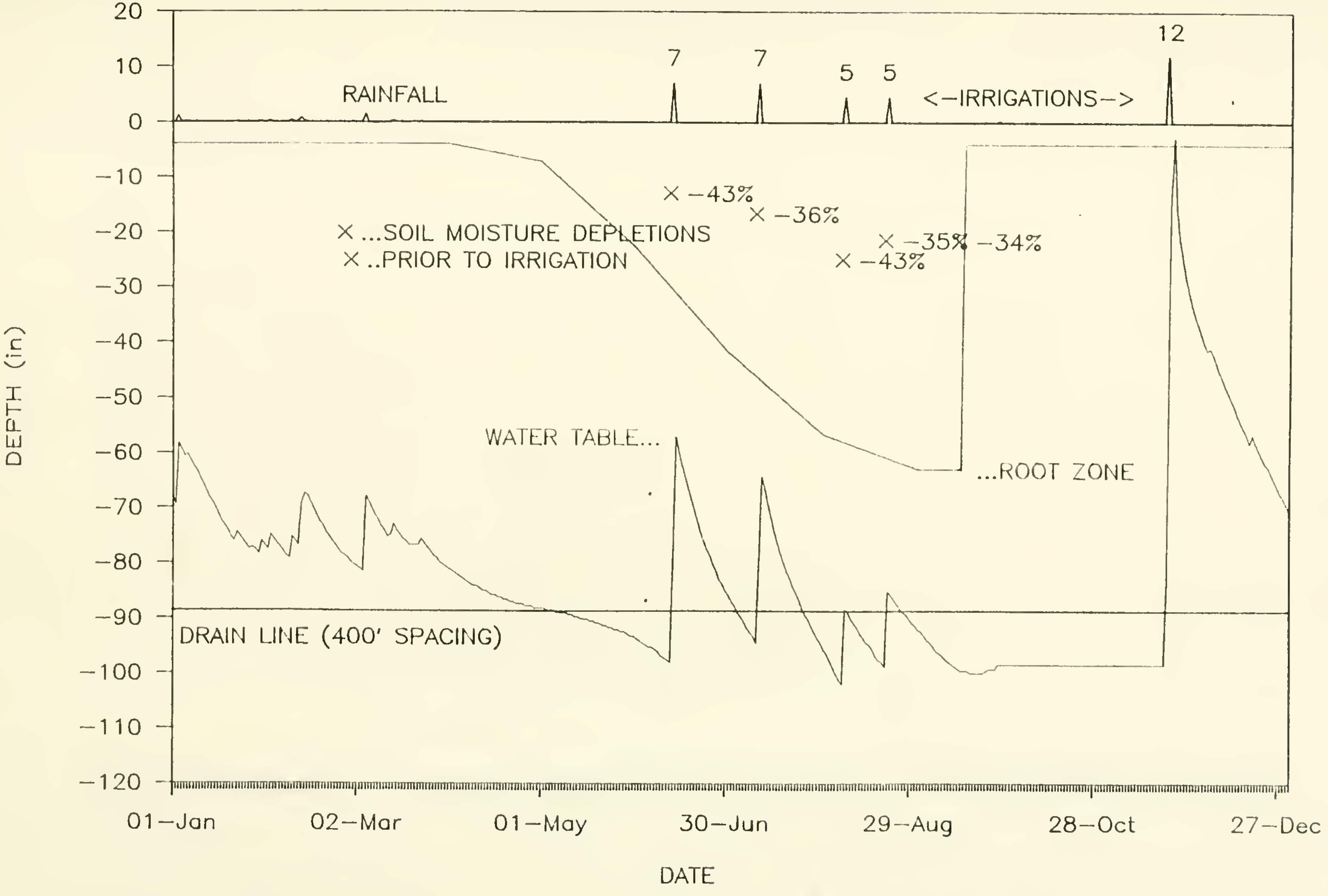


FIG. 19. UNCONTROLLED DRAINAGE W/MAN.

DRAINMOD-SWAP/ET RUN FOR SJVDP

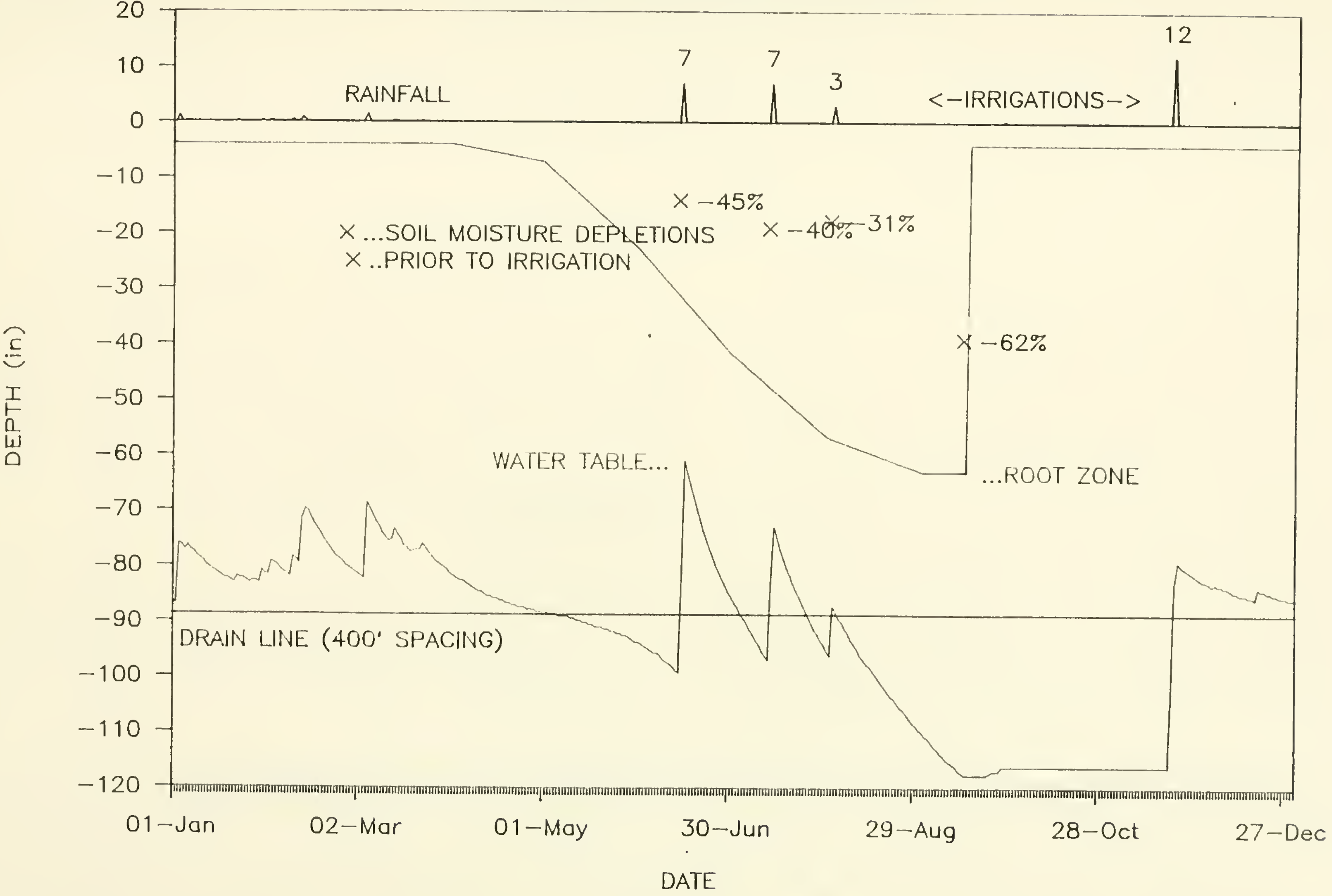
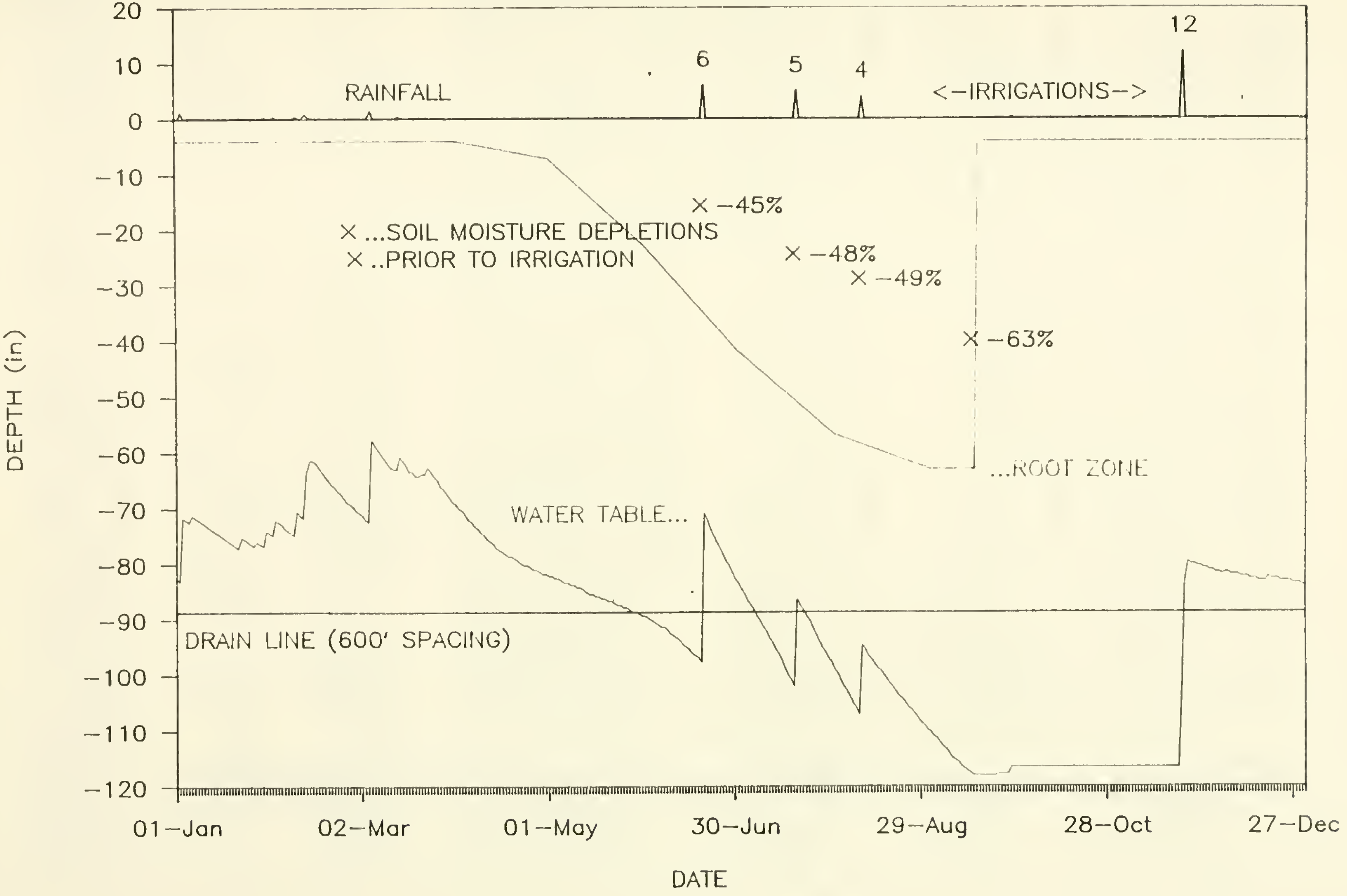


FIG. 20. UNCON. DRAINAGE W/MAN.(600')

DRAINMOD-SWAP/ET RUN FOR SJVDP



d. UNCONTROLLED DRAINAGE/WITH MANAGEMENT ("D") trial run

Figure 21 shows the results of this trial run. The effect of having management along with designing the drains for a wider spacing, 600 ft instead of 400 ft, was to decrease the irrigation plus rainfall by 7.0 in. to 33.8 in. and the drainage by 7.5 in. to 5.6 in. The leaching fraction was reduced to 16.6 percent.

e. WEIR CONTROLLED DRAINAGE W/MANAGEMENT ("E") trial run

Figure 22 shows the results of this trial run. The effect of having management plus weir control of the drainage was to reduce the irrigation plus rainfall by 11.0 in. to 30.8 in. and the drainage by 10.0 in. to 3.1 in. The leaching fraction was reduced to 9.9 percent.

f. FLOW CONTROLLED DRAINAGE W/MANAGEMENT ("F") trial run

Figure 23 shows the results of this trial run. The effect of having management plus control of the flow of the drain water was to reduce the irrigation plus rainfall by 7.5 in. to 34.3 in. and the drainage by 7.0 in. to 6.1 in. The leaching fraction was reduced to 17.8 percent.

g. Trends established from the trial runs

One of the areas targeted as having the greatest potential for savings in applied water and reduction in drain water is the preseason irrigation. An obvious result of these trial runs is that when the root zone has been dried down such as for the defoliation of cotton, a large irrigation will be necessary. If this irrigation can be made with a high uniformity, then the management of the seasonal irrigations becomes the key to the reduction in the drain flows.

Another of the outcomes of these runs was the importance of managing water on a yearly basis and not on an event basis. Again, the preseason irrigation affect points to this. Further evidence is when a final seasonal irrigation would be required early in order to achieve the desired depletion at defoliation.

The weir setting appeared to reduce drain flows the most. A further reduction in the drainage coefficient, produced by a smaller orifice, could offer the same savings under the flow control scheme.

Based on the drain flow hydrographs shown in Figure 24, the flow controlled drainage system did the best job of evening out the discharge rate per month. A concurrent trend was that the more the total flow was reduced, the more likely it will be that the drains will stop flowing for a significant period of the summer.

FIG. 21. UNCON. DRAIN W/MAN.(SHALLOW)

DRAINMOD–SWAP/ET RUN FOR SJVDP

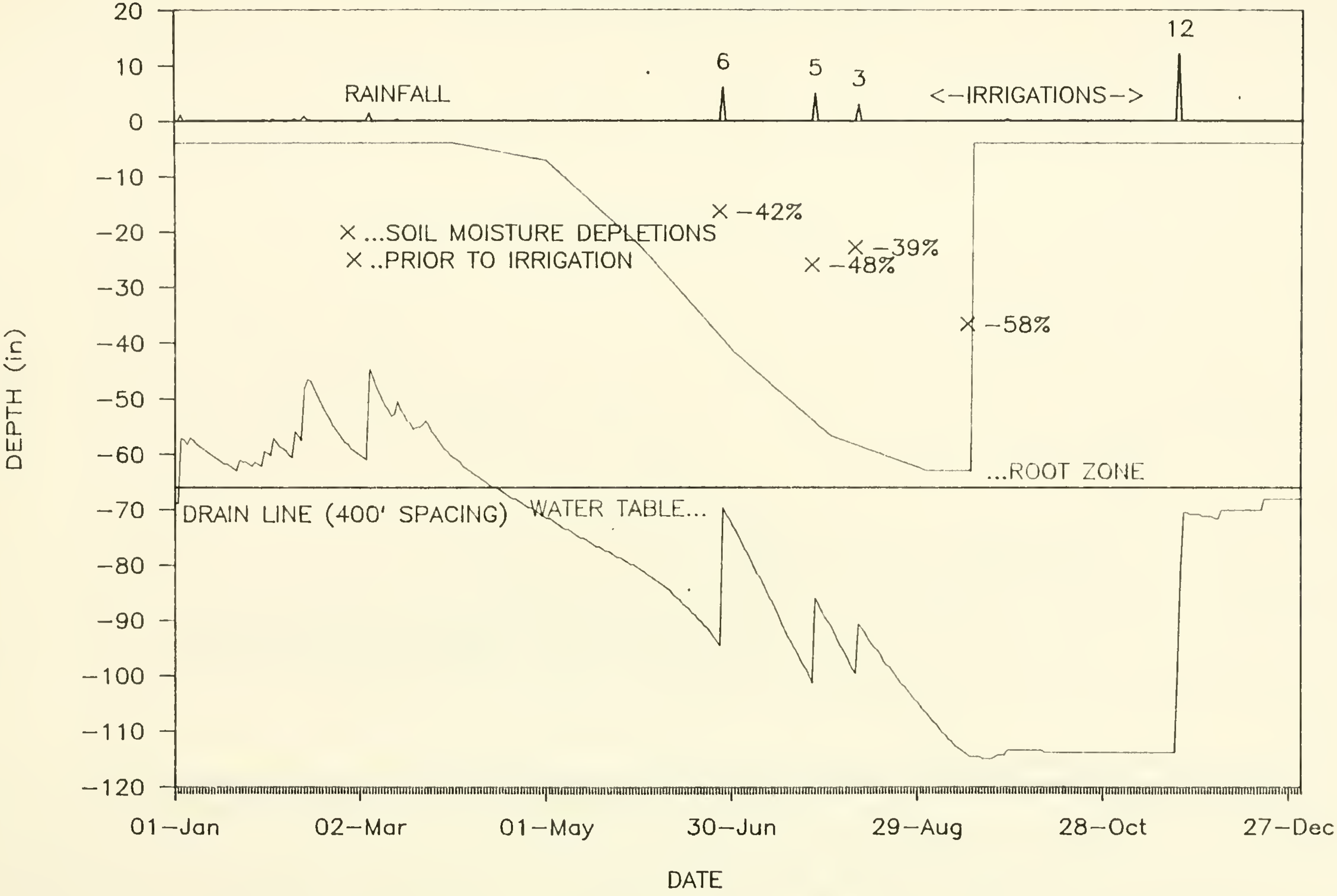


FIG. 22. WEIR CON. DRAIN. W/MAN.

DRAINMOD–SWAP/ET RUN FOR SJVDP

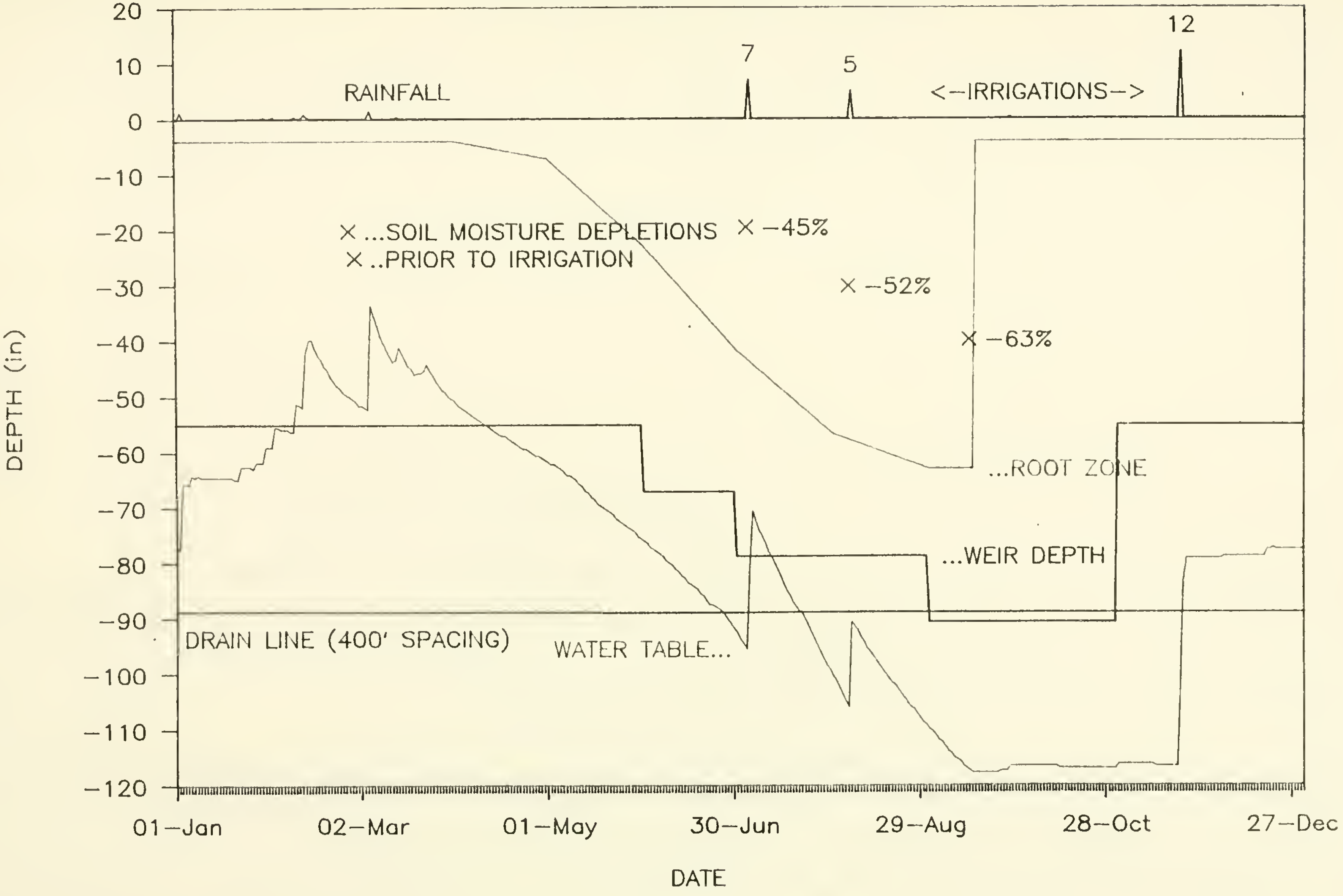


FIG. 23. FLOW CON. DRAIN. W/MAN.

DRAINMOD–SWAP/ET RUN FOR SJVDP

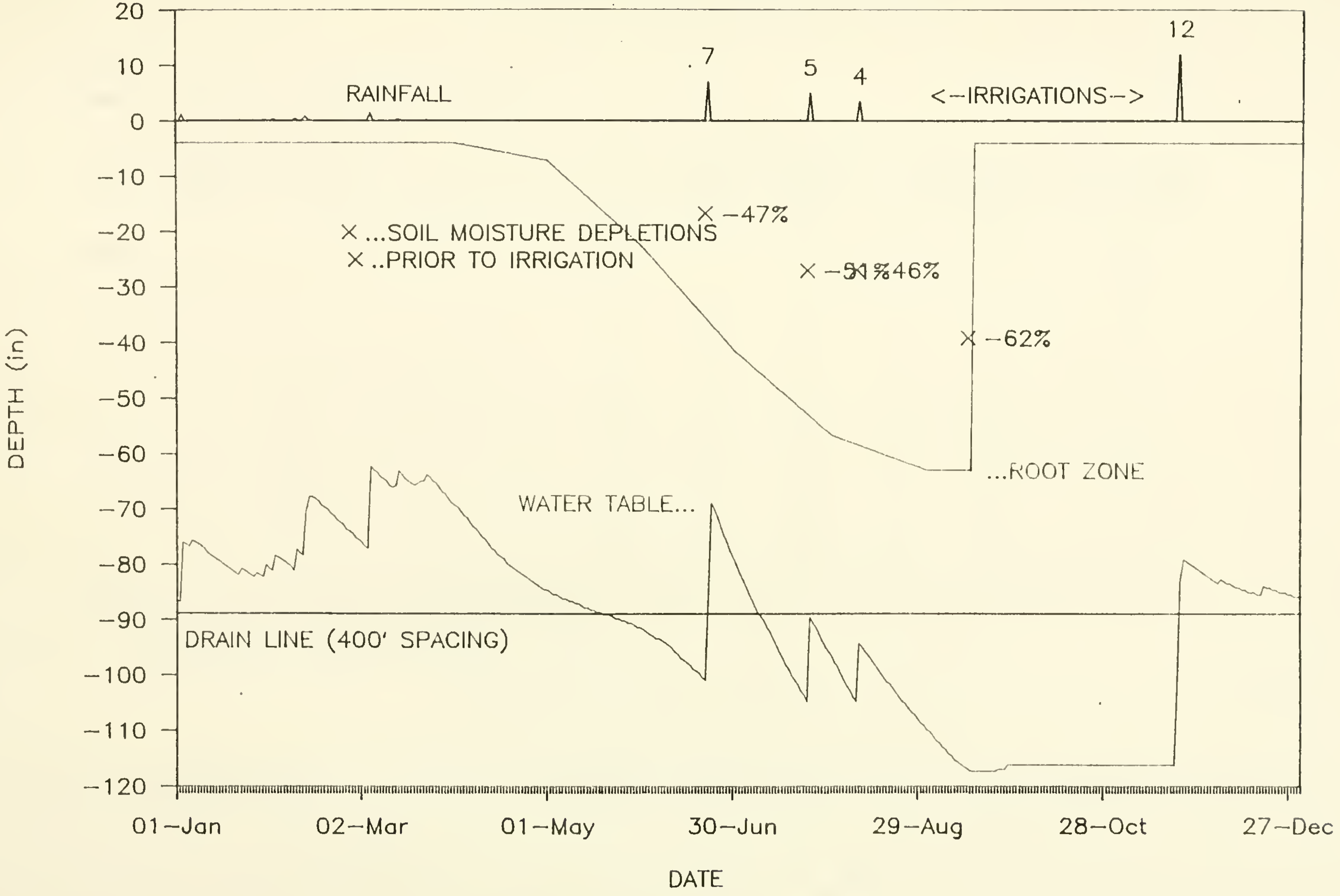


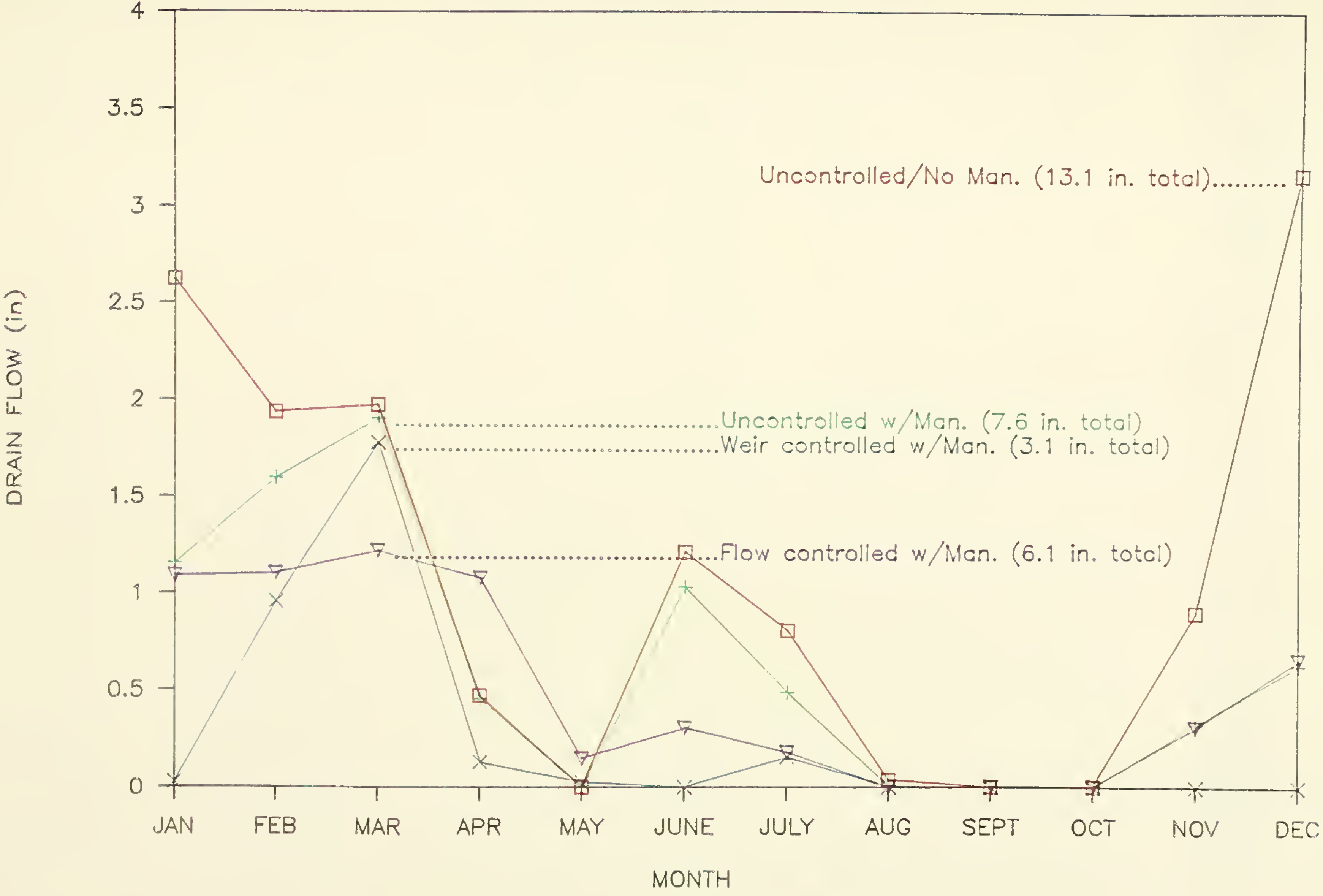
TABLE 5. COMPARISON OF DRAINMOD-SWAP/ET SIMULATIONS

	SYSTEM CHARACTERISTICS				TRIAL RUN RESULTS							
TRIAL RUN	MANAGED (Y/N) *	CONTROL METHOD	DRAIN SPACING (ft)	DRAIN DEPTH (ft)	IRRIGATION + RAIN (in)	INFILTRATION (in)	SURFACE RUNOFF (in)	EVAPOTRANSPIRATION (in)	UPFLUX (in)	CONTRIB. OF UPFLUX TO ET	DRAINAGE (in)	LEACHING FRACTION (%)
"A"	N	NONE	400	7.4	41.9	40.8	1.1	28.1	2.6	9.1%	13.1	32.2%
"B"	Y	NONE	400	7.4	35.8	35.9	0.0	28.3	1.7	6.1%	7.6	21.2%
"C"	Y	NONE	400	5.5	32.8	32.8	0.0	28.3	3.3	11.8%	4.5	13.8%
"D"	Y	NONE	600	7.4	33.8	33.8	0.0	28.4	1.7	6.0%	5.6	16.6%
"E"	Y	WEIR	400	7.4	30.8	30.8	0.0	28.5	4.3	15.2%	3.1	9.9%
"F"	Y	FLOW	400	7.4	34.3	34.3	0.0	28.3	1.7	5.9%	6.1	17.8%

* - Management based on irrigation scheduling with SWAP/ET and the performance of system evaluations.

FIG. 24. MONTHLY DRAIN FLOWS

DRAINMOD-SWAP/ET RUNS FOR SJVDP



In general, the trial runs verified that the DRAINMOD-SWAP/ET model has the potential to be a valuable tool in determining the best opportunities for drainage flow reductions in the study area.

V. RESEARCH PROGRAM FOR PHASE II

A. FIELD STUDIES TO BE PERFORMED

The studies to be performed under Phase II will be in two parts, in-field trials and computer simulations. The in-field studies will involve applying the DRAINMOD-SWAP/ET program along with system evaluations and controlling of the drain flows. The method of control will be either with weirs or orifices. The selection of method will be field specific. An attempt will be made to select fields that can be split as controlled vs. non-controlled. If the situation permits, the controls for each study field will be installed prior to the preseason irrigation this fall. If not, the fields will be "managed" the first cropping year of the study, and the controls will be installed prior to the second year. An attempt will also be made to select nearby fields that will not be managed or controlled. The purpose of these fields will be as checks for program evaluation.

The computer simulation part of these studies will have the primary purpose of evaluating opportunities that are not within the scope of this research program. These studies will evaluate, based on the field studies, the potential for new drainage system design including drain spacing and depth.

B. MONITORING REQUIREMENTS FOR MANAGING DRAINAGE REDUCTION

A key component of managing the drainage flow reduction program will be field monitoring of the various parameters that are inputs and outputs to DRAINMOD-SWAP/ET. The inputs are necessary to make DRAINMOD-SWAP/ET model what is happening in the field. Monitoring of the output parameters is necessary to calibrate and verify the accuracy of the model.

1. Climatic data and soil moisture

A nearby CIMIS or IMS weather station will gather daily temperature, humidity, wind, solar radiation, and rainfall data as inputs to the SWAP/ET modified Penman calculation of evapotranspiration potential (ETp). Crop coefficients based upon UC research and JML experience will be used to convert ETp to ET. Soil moisture conditions will be monitored twice a week using both the hand feel method at four locations in each field.

2. Irrigations

The quantity of irrigation water applied during each irrigation will be measured. Since the water districts in the study area do not measure water on a field by field basis, it will be necessary to set up measurement devices for each of the study fields. Theses devices may include the installation of weirs, gated pipe

flow meters, and/or float level recorders. The goal will be to measure the water applied to each field as accurately as each situation will allow. This need will be factored into the selection of the test fields.

3. Drainage flows (surface and sub-surface)

The surface runoff water from each field will be measured with the use of Parshall flumes. These will be set at the corner of each field and will be monitored, when possible, using Stevens float level recorders. An attempt will be made to quantify the subsurface flows coming from selected areas in each test field. These areas will be selected according to the layout of the existing drainage system. The goal will be to measure the flow of drain water at locations that will best reflect the results of each treatment. The method for measuring the drain flow will be to use either an overflow weir or an orifice. In either case, readings will be taken on a frequent enough basis to characterize the flow hydrograph.

4. Water table (levels and quality)

Based on the layout of each drainage system, a grid of observation wells will be installed. The goal of the selected grid will be to enable to characterize the fluctuations in the water table on an areal basis for each field. These wells will be surveyed for location and elevation, in order to be able to re-install them at the same location for each of the test years. They will be monitored manually as a regular part of the field monitoring process.

5. Canal seepage and net inflow or outflow

The flow of water across the "field boundary" that extends down to the barrier, as well as deep seepage losses, will be the most difficult measurements required in order to complete the measurement of the water balance. Canal seepage will be estimated through the measurement of flow from interceptor drains or a combination of the selective placement of piezometers and the measurement of the lateral and vertical hydraulic conductivities of each soil layer. The lateral inflow, lateral outflow, deep seepage, and upflow can be combined into one term: the net inflow (or net outflow if negative). A volume balance for the field will be used to calculate the net inflow or outflow. This can be done since measurements will be made of all the other components of the volume balance.

6. Soil chemistry

To check for an annual change of soil salinity and boron in the fields, each foot of soil will be sampled from the auger holes for the observation wells (which will be resurveyed in and

reinstalled each year). The EC, boron, and SAR will be analyzed for each foot for each hole. A Kriging process will be used to map salinity trends in each field. To check for a change in the salinity and boron levels during the growing season, 0-5 foot composite soil samples will be taken in one foot increments between each irrigation on a diagonal transect of the field.

VI. AFFECTS OF FLOW REDUCTION ON WATER QUALITY

Analyzing the effects of subsurface flow reduction on water quality is extremely complex. A proper treatment of the subject requires modeling solute transport in a drainage system including the many chemical reactions which occur in the unsaturated and saturated zone. Finite element flow models may be better than DRAINMOD when looking at solute transport. This study does not attempt to answer questions about the affects of flow reduction on water quality, but does touch on some of the concepts and issues involved.

A mass balance equation in the crop root zone has the same form for salinity, boron, and selenium:

Mass in inflow - Mass of sinks + Mass of sources =
Mass in outflow

Sinks occur where the constituent precipitates into an insoluble form or is taken up by the plant. Sources occur where minerals present in the soil dissolve or if lateral inflow or upflux from the water table bring in more mass.

When the Mass going to sinks and coming from sources are equal to zero or cancel each other out, the Mass in the inflow becomes equal to the Mass in the outflow. This means that regardless of the amount of subsurface drainage flow reduction that occurs, the mass of the constituent in the outflow remains the same. This assumption however probably does not apply to the constituents of concern in the drainage study area.

A. SALINITY

Salts are imported in the irrigation water in the drainage study area. If the leaching fraction were to be decreased, the concentration of salts in the root zone would increase and the likelihood of salts precipitating would also increase. As this occurs, the mass in the outflow would be reduced. Another factor to consider is that the soils in the study area tend to contain precipitated gypsum from past salinization. As low salt irrigation waters are brought in, the gypsum dissolves and thus becomes a salt source. A reduction in the leaching fraction would also tend to reduce this dissolution and the mass in the outflow would also be reduced. Examples demonstrating these two effects are discussed in more detail in "Farm Water Management Options for Drainage Reduction" pages 3-16 through 3-21.

Oster and Tanji (1985) show results of studies done on a number of different water sources where the mass in the outflow-decreased with decreasing leaching fraction due to the above effects. The long term affect on the soils of increased precip-

itation of salts or decreased dissolution of salts is a question which has not been answered.

B. BORON

Boron is also being brought in at small concentrations with the irrigation water. It is also present in the soils (in soluble and insoluble form) and in the water table due to concentration by evaporation. The sources and sinks of boron are not well understood. It is possible that decreased leaching fractions would decrease the dissolution of boron and thus decrease the mass of boron in the outflow.

C. SELENIUM

Selenium is not being brought in with the irrigation water in large quantities. Deverell (1987) suggests that the selenium which is coming out of the drainage systems is coming from the soil solution and shallow groundwater which have been concentrated by evaporation. It is possible that decreased leaching fractions would decrease the dissolution of selenium and thus decrease the mass in the outflow. Considering the selenium which has already been leached from the soils, a decrease in leaching fraction would slow down the rate at which the selenium containing groundwater will reach the drains and theoretically reduce the mass in the outflow.

VII. FLOW RELEASE CONSIDERATIONS

A. AT SUMP TREATMENT

Because of the variable nature of specific field drain flows, any water treatment plant at the field, or sump level, will need a capacity to handle the maximum possible drain flow. The flow control or weir control scenarios can make significant reductions in the required capacity of at sump treatment plants.

Careful consideration of the crop rotation is needed when considering the methods available for limiting the peak flows. An example of the variation that can occur is seen in the Pillsbury and Johnston (1965) study. For Field 5, the peak flows for 1960, 61 and 62 were 4.53, 21.4 and 2.16 gpm/100 ft of tile line.

B. REGIONAL TREATMENT

The accumulation of flows from different fields with a variety of crops will help to even out the flow variation to a regional treatment plant. However, as witnessed in the flow hydrographs for Broadview Water District (Day and Nelson, 1987) there is currently a wide fluctuation in the monthly flows over large areas. Therefore, any efforts to reduce the peak flows at the field level could also effect a reduction over a region.

C. EVAPORATION OR REGULATION RESERVOIRS

When evaporation ponds or regulating reservoirs are used in a treatment process, the average flow from the drains over a longer time period becomes more important than the peak instantaneous flow. The trend for decreased flows over the summer, along with reduced total flows of drain water, suggests that the size of these structures could be reduced with a flow reduction program.

D. RELEASES TO THE RIVER

Since the best opportunity for mixing drain water with river water will be in the spring, the flow controlled drain systems offer the best advantage. This is because of the greater evening out of the monthly flow peaks and the resulting relative increase in flows in May.

VIII. CURRENT VIEW ON THE POTENTIAL FOR DRAINAGE REDUCTION IN THE STUDY AREA

Figure 25 portrays the various components which are factors in the amount of flow which comes out of subsurface drains. Solving a volume balance equation for subsurface drainage flow results in the following equation:

$$Qss = (Qf + RF + CS + Li) - (WT + SM) - (RO + ET + DF + Lo)$$

Where Qss = Flow from subsurface drains
Qf = Flow to the field for irrigation
RF = Rainfall
CS = Canal seepage
Li = Lateral inflow
WT = Change in water table
SM = Change in soil moisture
RO = Runoff from field
ET = Evapotranspiration
DS = Deep flow (could be positive or negative)
LO = Lateral outflow

If the lateral inflow (Li), deep flow (DF), and the lateral outflow are replaced by one term called the net inflow (NIF = Li - DS - Lo), the change in water table and soil moisture equal zero (WT + SM = 0), and the average amount infiltrated from irrigation is inserted (AAI = Qf - RO), the equation simplifies to:

$$Qss = (AAI + RF + CS + NIF) - ET$$

For comparison, recall the equation for net deep percolation (NDP) from the previous discussion:

$$NDP = (AAI + RF) - ET$$

When these two equations are combined, a relation for subsurface drain flow versus net deep percolation results:

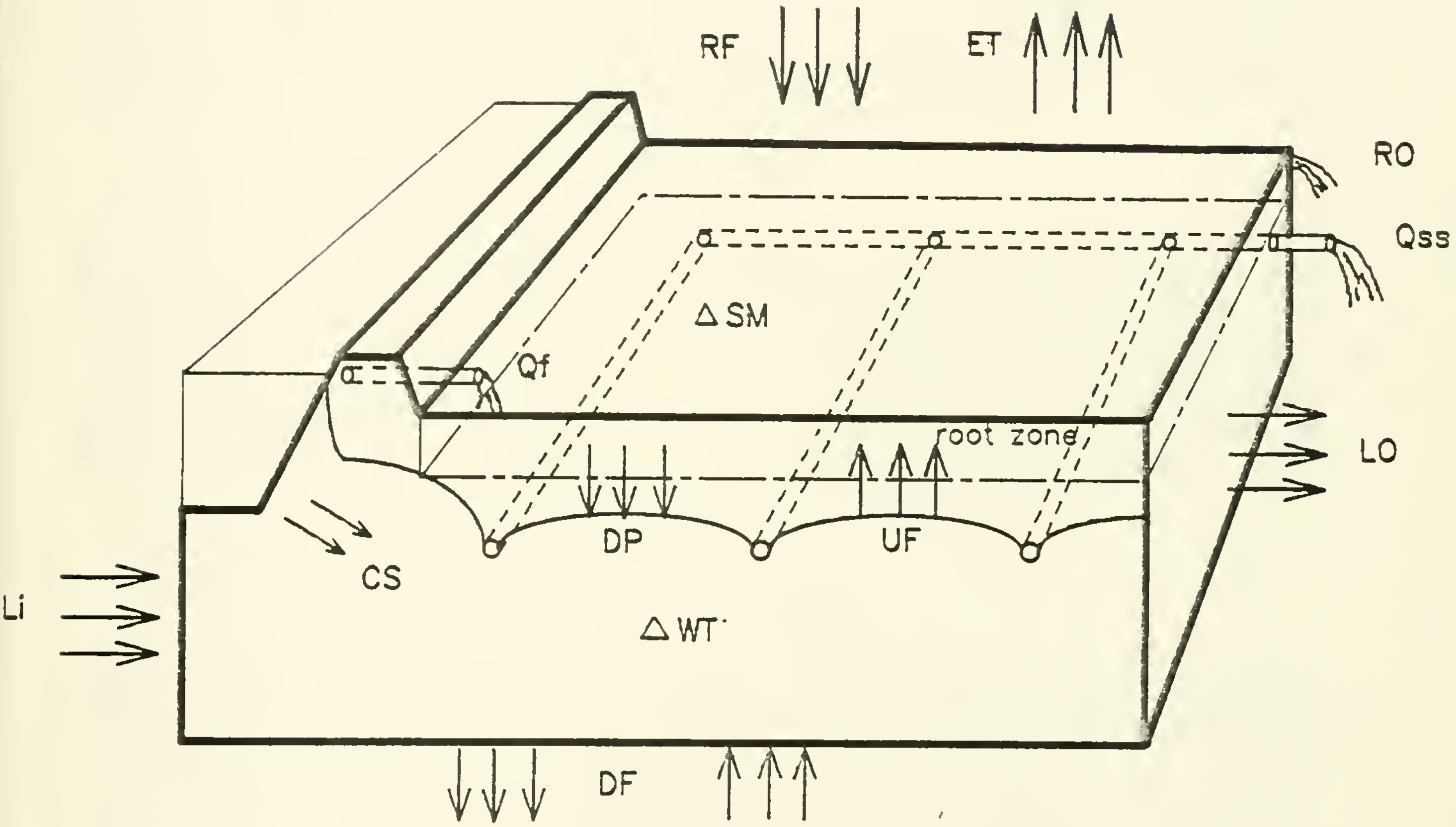
$$Qss = NDP + CS + NIF$$

A. COMPONENTS OF DRAINAGE FLOWS WHICH WILL NOT BE REDUCED BY SCHEME

The goal of the subsurface drainage flow reduction program outlined in this report is to reduce the net deep percolation. The canal seepage and net inflow components (CS and NIF) would not be affected by the program. The amount of canal seepage in the drainage study area is not known. Another component of subsurface flows which could not be reduced by the program is the deep percolation needed to reclaim the existing soils.

FIGURE 25

COMPONENTS OF SUBSURFACE DRAINAGE



ET = Evapotranspiration
RF = Rainfall
RO = Runoff
Qss = Flow from subsurface drains
ΔSM = Change in soil moisture
Qf = Flow to the field (irrigation water)
Li = Lateral inflow
CS = Canal seepage
DP = Deep percolation
UF = Upflux from water table
Lo = Lateral Outflow
ΔWT = Change in water table
DF = Deep flow

The amount of net inflow to the subsurface drains in the study area is also not known. This no doubt varies greatly from field to field. Flow records from some of C.C.I.D.'s drains show huge net inflows (Day, 1986) whereas Broadview's show little (Day and Nelson, 1986). Some of Chang's work with DRAINMOD and data from Pillsbury and Johnston (1965) for drainage systems in Firebaugh Canal Company actually showed large deep seepage losses and thus a net outflow. Much upslope development has occurred since the 1965 research was done, however, and the situation may have changed. Summing of the net inflow to the study area's subsurface drains is one of the keys to determining the amount of subsurface drainage reduction that is possible.

B. LIMITATIONS OF LEACHING REQUIREMENT

Because of the relatively low salinity irrigation water used in the drainage study area, calculated leaching requirements are very low. The inaccuracy involved in measuring the amount of water applied to a field is even greater than the leaching requirement. For practical purposes, a leaching requirement of 1 acre-inch per acre can be used. It is important to remember however that deep percolation due to lack of distribution uniformity must be added to the leaching requirement when figuring the minimum net deep percolation possible.

C. DISTRIBUTION UNIFORMITY LIMITATIONS

Limitations in the distribution uniformity (DU) which can be achieved by the existing irrigation methods will be the largest factor which will limit the minimum net deep percolation that can be achieved without long term salt buildup in the soils. There has been no comprehensive assessment of the current annual DU's which exist in the drainage study area nor of the DU's which can be achieved. The Los Banos office of SCS, through the California Department of Water Resources' mobile lab program, has evaluated many individual irrigation events in the Panoche Water District area. In addition, private consultants, including JMLord, Inc., have performed many more in the neighboring Westland's Water District on the same soil types as occur in the study area. These evaluations should be developed as a data base to evaluate the limitations that distribution uniformity has on subsurface drainage reduction.

D. CROP LIMITATIONS

The literature review done on water table contribution to crop ET and JMLord, Inc.'s experience suggest that there is no crop which is not able to use water from the water table. Practically, however, the shallow rooted and salt sensitive vegetable crops such as tomatoes, melons, and peppers may not be good choices for

controlled drainage schemes which encourage large contributions from the water table. These crops are currently farmed on about 17 percent of the study area's acreage. The remaining crops, cotton, grain, alfalfa, sugar beets and safflower are good candidates for controlled drainage schemes. The irrigation management schemes can apply to all of these crops.

E. PRACTICAL LIMITATIONS

Practical limitations to the proposed drainage flow reduction scheme are mainly in three categories: drainage system configurations problems, grower implementation, and institutional.

1. Drainage system configuration problems

The drainage flow reduction program proposed assumes one field with its own relief sub-surface drainage system having the same spacing and uniform soil properties and uniform water table depths throughout the field. There are very few existing tile drainage systems which actually meet all of these conditions. Many fields do not have complete relief drainage. Examples of this are fields with only one interceptor drain or a baseline with no laterals. Controlled drainage could not be practiced on such fields without installing complete relief drainage. The irrigation management practices could be employed. However, without adequate natural or man made subsurface drainage, salinity problems will continue to worsen.

Variability in soil, water table, or drain spacings would be handled by managing the irrigations for the limiting condition. In other words, when the soil reaches the MAD in a certain portion of the field, it is time to irrigate, even if the rest of the field has not reached MAD. The area which reaches MAD first will likely be the area where contribution to ET from the water table is the least. In some fields, the variability problems may prevent controlled drainage from being employed. The irrigation management practices could still be employed.

Drainage systems which drain more than one field pose special design problems for controlled drainage. An example would be systems which have relief drains that run through two fields. Flow control systems would be very difficult to employ on the downstream field because it would restrict the upstream field at the same time. Weir control might work in these situations however. Again, the irrigation management practices could be employed on such fields with or without controlled drainage.

2. Farmer implementation

An expert can design and recommend a drainage flow reduction program which will do just the right thing, but getting the

theory put into practice in the field is often a big hurdle. Private consultants, the Co-operative Extension and the SCS have struggled with this problem for years. The key to getting the theory put into practice is to get the farm manager to 1.) understand why the recommendation is being given, 2.) believe that what is being recommended is the best thing for him to do to meet his goals (which is to maximize the profit of his operation), and 3.) understand what he needs to do in order to implement it. Doing the above requires educating the farm manager and two way communication between the consultant and farm manager. Personnel who have both the technical and communication skills to successfully consult the farm manager are required. This fact should not be overlooked when planning a regional drainage reduction program.

3. Institutional

Government or district entities can add constraints which may limit the ability to reduce sub-surface drainage flows with the proposed program. Inflexibility in irrigation delivery with respect to frequency, flow rate, or duration can cut into the effectiveness of the water management program. This is not perceived as a major problem in the drainage study area, however. Water delivery canals in all of Broadview Water District, Firebaugh Canal Company, and the major portion of Panoche Water District and Pacheco Water District have pump stations which already have been or can be automated to respond to the demand placed upon them. Such delivery systems are the most flexible.

Perhaps one of the largest problems, however, is that the irrigation districts pay the U.S.B.R. for all of the water they order, regardless of whether they use it or not. This gives the water district and the growers who compose the district no water cost incentive for improving irrigation management once the water is ordered. Refunds for water ordered but not used would eliminate this problem.

Drainage districts often discourage the farmers from running large amounts of tailwater into the district drains because of the silt load carried in. Often times, however, larger amounts of tailwater are produced when irrigations are managed to maximize distribution uniformity (because the water advances to the end of the field faster and contributes tailwater for a longer period of time). The restriction on tailwater may inadvertently limit the distribution uniformity which can be achieved in the field unless on-farm tailwater return facilities are installed.

F. CURRENT PROJECTIONS OF REDUCTION IN DRAINAGE VOLUME

Given the current state of knowledge and the current database of information available on the study area, it is impossible to

accurately project the amount of reduction which can be made in the flows from sub-surface drainage systems. This report has shown that a combined irrigation management and controlled drainage program can be designed using DRAINMOD and SWAP/ET on a field by field basis to reduce the net deep percolation to the minimum possible without promoting long term salt buildup (NDPmin). The NDPmin depends primarily upon the annual distribution uniformity which can be achieved. An example of how the NDPmin would be calculated for the drainage study area assuming no deep percolation for reclamation is as follows:

The weighted average growing season ET for the drainage study area calculates out to about 24 inches. If 3 inches were added for non-growing season ET, the total annual ET would be 27 inches. Assuming an average leaching requirement of 3.5%, a maximum attainable DUa of 80%, and an average rainfall of 6 inches, the NDPmin calculates out to 6.4 inches.

Again, the actual number to use for maximum attainable DUa is not known at this time.

Summing of the existing NDP for the drainage study area is needed before a calculation of the potential reduction in NDP can be made. This could be done by doing water accounting using accurate water delivery and drainage flow data. Then, summing of the canal seepage and net inflow (or net outflow, whichever is the case) would need to be done in order to calculate the reduction in subsurface drainage flow that is possible through an irrigation management and controlled drainage program.

IX. HOW TO IMPLEMENT REDUCTION

A. WHO WILL DESIGN THE FLOW REDUCTION HARDWARE AND MANAGEMENT STRATEGY FOR EACH FIELD AND ADVISE THE GROWER ON MANAGEMENT?

Since a sub-surface drainage flow reduction program requires an individualized approach to each field, the hardware and management strategy must be designed for each by individuals with expertise in irrigation management, drainage system design, irrigation evaluation, and salinity management. The same individuals should also be the ones to advise the grower on management of the system after it is installed. Qualified private consultants are one option while another is a government agency such as the SCS.

B. WHERE WILL FUNDS COME FROM TO PAY FOR DRAINAGE REDUCTION PROGRAM?

The question of how to pay for the hardware required, the design work, and the management work is difficult to answer at this time. Prevailing public opinion at this time places the burden on the farmer. If the drainage reduction program reduces his cost to dispose of subsurface drainage waters by more than it costs to do the reduction program, the program becomes his best option. It should not be overlooked that benefits of the drainage reduction program besides reduced drainage costs (water conservation, reduced fertilizer leaching, labor savings, increased yields) will also help offset the cost of the program.

C. WHAT WILL MOTIVATE THE GROWER TO REDUCE SUBSURFACE FLOWS?

The chief motivator of a farmer is maximizing the profit of the farming operation. The farmer will be motivated to reduce subsurface drainage flows when he sees that doing so will increase his profit by reducing his expenses and/or increase his yield. When drainage reduction becomes a better option economically than paying for the treatment and disposal of a larger volume of water is when the motivation will be there.

X. COSTS TO IMPLEMENT REDUCTION

A. DESIGN

The current cost for a private consultant to provide standard drainage investigation and design services ranges from $25 to $50 per acre depending upon the size of the area to be designed. This would also be the approximate price range for the first year of work to design the modifications and management strategy necessary for a drainage reduction program.

B. CONSTRUCTION

Where controlled drainage is employed, the initial cost to furnish and install the modifications will be highly site dependant. Where there are many laterals which need individual control and where the field slope is steep, more drain control gates will be needed and the cost will be more. Flow control methods currently will cost more than weir control. The development of cheaper in-line flow control valves is needed to make them a viable option.

Rough cost estimates for two fields were made on the extremes of the cost spectrum. The first was on a field with 400 foot drain spacing, a 0.005 ft/ft slope, and weir control. The estimated cost was $90 per acre. The second field had only two weir control structures which controlled the entire field (800 foot drain spacing and a 0.002 ft/ft slope), the cost was $12 per acre.

C. MANAGEMENT

The current price for irrigation management services which include two irrigation evaluations, irrigation scheduling, and production of reports on improving irrigation efficiency ranges from $16 to $30 per acre depending on the field size. More field and lab work would be required for the drainage flow reduction management services program. Depending on the reporting requirements, the cost range is estimated to be $25 to $40 per acre for the first year with some reduction in succeeding years.

D. MONITORING

The cost of monitoring most of the parameters is included in the cost of management services. Flow meters for irrigation and for measuring drain flows would be above and beyond the cost given however.

E. MAINTENANCE

The maintenance of the controlled drainage equipment would be very small when corrosion and impact resistant materials are used

in the construction. If corrosion or impact from farm traffic occur, the expected life of the components should be reduced in the economic analysis.

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APPENDIX A

```
******************************************************************************

                                  D R A I N M O D

                          VERSION: NORTH CAROLINA MICRO 3.0
                      LAST UPDATE: MAY 1987
                         LANGUAGE: MS FORTRAN v 4.0

             DRAINMOD IS A FIELD-SCALE HYDROLOGIC MODEL DEVELOPED FOR
             THE DESIGN OF SUBSURFACE DRAINAGE SYSTEMS. THE MODEL WAS
             DEVELOPED BY RESEARCHERS AT THE DEPT. OF BIOLOGICAL AND
             AGRICULTURAL ENGINEERING. NORTH CAROLINA STATE UNIVERSITY
             UNDER THE DIRECTION OF R. W. SKAGGS.

******************************************************************************




                      *******************
                      * D R A I N M O D *
                      *******************

   DATA READ FROM INPUT FILE dr.

                          TITLE OF RUN
                          ************


  SJVDP sample run (9/30/87)
  Uncontrolled drainage / managed (600' spacing)



                         CLIMATE INPUTS
                         ******* ******

       DESCRIPTION                                    (VARIABLE)      VALUE   UNIT
  --------------------------------------------------------------------------------
  FILE FOR RAINDATA ..........................................irriot.rai
  FILE FOR TEMPERATURE/PET DATA ..............................etido.tem
  RAINFALL STATION NUMBER...........................(RAINID)      9362
  TEMPERATURE/PET STATION NUMBER....................(TEMPID)      9362
  STARTING YEAR OF SIMULATION...................(START YEAR)      1986    YEAR
  STARTING MONTH OF SIMULATION.................(START MONTH)         1    MONTH
  ENDING YEAR OF SIMULATION.......................(END YEAR)      1986    YEAR
  ENDING MONTH OF SIMULATION.....................(END MONTH)        12    MONTH
  TEMPERATURE STATION LATITUDE....................(TEMP LAT)     37. 0    DEG.MIN
  HEAT INDEX.............................................(HID)    100.00


  ET MULTIPLICATION FACTOR FOR EACH MONTH
       1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00

1                                 DRAINAGE SYSTEM DESIGN
                                  **********************

                                *** CONVENTIONAL DRAINAGE ***

           JOB TITLE:

                   SJVDP sample run (9/30/87)
                   Uncontrolled drainage / managed (600' spacing)
```

```
                     STMAX =  .20 CM                          SOIL SURFACE
+           __/)__________________________________________________________________/)__
                  :                                                   :
                  :                                                   :
                  :                                                   :
                  :                                                   :
                  :                                                   :
            ADEPTH =610. CM                                       DDRAIN =225. CM
                  :                                                   :
                  :                                                   :
                  :      O-------------SDRAIN =18288. CM -----------O -
                  :                                                   :
                  :                                                   :
                  :                                               HDRAIN =318. CM
                  :                                                   :
                  :                                                   :
            - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                  :
                  :
                  :
                  :                                        IMPERMEABLE LAYER
+           --------------------------------------------------------------------
            ////////////////////////////////////////////////////////////////////


                        DEPTH       SATURATED HYDRAULIC CONDUCTIVITY
                        (CM)                     (CM/HR)

                      .0 -  183.0                 3.300
                   183.0 -  610.0                11.400


  DEPTH TO DRAIN = 225.0 CM
  EFFECTIVE DEPTH FROM DRAIN TO IMPERMEABLE LAYER = 318.3 CM
  DISTANCE BETWEEN DRAINS = 18288.0 CM
  MAXIMUM DEPTH OF SURFACE PONDING =   .20 CM
  EFFECTIVE DEPTH TO IMPERMEABLE LAYER =  543.3 CM
  DRAINAGE COEFFICIENT(AS LIMITED BY SUBSURFACE OUTLET) =   .26 CM/DAY
  ACTUAL DEPTH FROM SURFACE TO IMPERMEABLE LAYER = 610.0 CM
  SURFACE STORAGE THAT MUST BE FILLED BEFORE WATER
    CAN MOVE TO DRAIN =  .10 CM
  FACTOR -G- IN KIRKHAM EQ. 2-17 = 8.38

  WIDTH OF DITCH BOTTOM =     .1 CM
  SIDE SLOPE OF DITCH (HORIZ:VERT) =   .10 : 1.00

  INITIAL WATER TABLE DEPTH = 210.0 CM
1
      DEPTH OF WEIR FROM THE SURFACE
      ------------------------------
  DATE          1/  1    2/  1    3/  1    4/  1    5/  1    6/  1
  WEIR DEPTH    230.0    230.0    230.0    230.0    230.0    230.0

  DATE          7/  1    8/  1    9/  1   10/  1   11/  1   12/  1
  WEIR DEPTH    230.0    230.0    230.0    230.0    230.0    230.0


  DRAINMOD has changed the final entry in the SOIL WATER CHARACTERISTIC TABLE to

            X(IVREAD)    XVOL(IVREAD)    FLUX(IVREAD)
              1000.          100.            0.0
```

```
 (entered values had WTD <1000. or vol.drained >100.)

** SEE DRAINMOD USERS MANUAL FOR EXPLANATION **

                       SOIL INPUTS
                       ***********


                         TABLE 1

                      DRAINAGE TABLE
                 VOID VOLUME   WATER TABLE DEPTH
                    (CM)            (CM)
                      .0              .0
                     1.0            67.1
                     2.0            88.2
                     3.0           103.4
                     4.0           117.1
                     5.0           129.8
                     6.0           142.2
                     7.0           154.0
                     8.0           164.8
                     9.0           175.5
                    10.0           186.3
                    11.0           197.1
                    12.0           207.3
                    13.0           217.4
                    14.0           227.4
                    15.0           237.4
                    16.0           247.4
                    17.0           257.5
                    18.0           267.5
                    19.0           277.5
                    20.0           287.6
                    21.0           297.6
                    22.0           306.8
                    23.0           315.6
                    24.0           324.5
                    25.0           333.4
                    26.0           342.3
                    27.0           351.2
                    28.0           360.1
                    29.0           369.0
                    30.0           377.9
                    35.0           422.3
                    40.0           466.7
                    45.0           511.2
                    50.0           555.6
                    60.0           644.5
                    70.0           733.4
                    80.0           822.2
                    90.0           911.1
                         TABLE 2

  SOIL WATER CHARACTERISTIC VS VOID VOLUME VS UPFLUX

    HEAD       WATER CONTENT    VOID VOLUME      UPFLUX
    (CM)          (CM/CM)           (CM)         (CM/HR)
      .0           .5000             .00          1.0000
    10.0           .4960             .02          1.0000
    20.0           .4920             .08           .4900
    30.0           .4880             .18           .3200
    40.0           .4840             .32           .1800
    50.0           .4800             .50           .1200
```

```
                 60.0          .4700            .75          .0900
                 70.0          .4600           1.10          .0700
                 80.0          .4500           1.55          .0500
                 90.0          .4400           2.10          .0400
                100.0          .4300           2.75          .0300
                110.0          .4270           3.48          .0250
                120.0          .4240           4.21          .0200
                130.0          .4210           5.02          .0167
                140.0          .4180           5.82          .0133
                150.0          .4150           6.63          .0100
                160.0          .4120           7.56          .0080
                170.0          .4090           8.49          .0060
                180.0          .4060           9.41          .0040
                190.0          .4030          10.34          .0020
                200.0          .4000          11.27          .0000
                210.0          .3981          12.27          .0000
                220.0          .3961          13.26          .0000
                230.0          .3942          14.26          .0000
                240.0          .3923          15.26          .0000
                250.0          .3903          16.26          .0000
                260.0          .3884          17.25          .0000
                270.0          .3865          18.25          .0000
                280.0          .3845          19.25          .0000
                290.0          .3826          20.24          .0000
                300.0          .3807          21.24          .0000
                350.0          .3710          26.87          .0000
                400.0          .3667          32.49          .0000
                450.0          .3624          38.12          .0000
                500.0          .3581          43.74          .0000
                600.0          .3494          54.99          .0000
                700.0          .3408          66.25          .0000
                800.0          .3316          77.50          .0000
                900.0          .3225          88.75          .0000


                   GREEN AMPT INFILTRATION PARAMETERS
                      W.T.D.          A         B
                       (CM)        (CM)      (CM)
                        .000       .000     1.000
                      30.000       .400     1.200
                      60.000       .600     1.400
                     120.000       .800     1.600
                     150.000      1.000     1.800
                     500.000      1.200     2.000
                    1000.000      1.200     2.000
1                              TRAFFICABILITY
                               **************

                                                             FIRST       SECOND
    REQUIREMENTS                                             PERIOD      PERIOD
       -MINIMUM AIR VOLUME IN SOIL (CM):                      3.00        3.00
       -MAXIMUM ALLOWABLE DAILY RAINFALL(CM):                 1.00        1.00
       -MINIMUM TIME AFTER RAIN BEFORE TILLING CAN CONTINUE:  2.00        2.00

    WORKING TIMES
       -DATE TO BEGIN COUNTING WORK DAYS:                     2/ 1       12/32
       -DATE TO STOP COUNTING WORK DAYS:                      4/ 1       12/31
       -FIRST WORK HOUR OF THE DAY:                             6           7
       -LAST WORK HOUR OF THE DAY:                            20          17


                                    CROP
```

```
SOIL MOISTURE AT CROP WILTING POINT =     .18

HIGH WATER STRESS:  BEGIN STRESS PERIOD ON    4/ 1
                    END STRESS PERIOD ON      9/30
                    CROP IS IN STRESS WHEN WATER TABLE IS ABOVE  90.0 CM

DROUGHT STRESS:     BEGIN STRESS PERIOD ON    4/ 1
                    END STRESS PERIOD ON      9/ 1




                              MO    DAY   ROOTING DEPTH(CM)
                               1     1          10.0
                               4     1          10.0
                               5     1          18.0
                               6     1          58.0
                               7     1         106.0
                               8     1         144.0
                               9     1         160.0
                               9    15         160.0
                               9    16          10.0
                              12    31          10.0


                              WASTEWATER IRRIGATION
                              *********************


      WASTEWATER IRRIGATION IS SCHEDULED:
      -----------------------------------
FIRST DAY OF SURFACE IRRIGATION =  0
INTERVAL BETWEEN SURFACE IRRIGATION DAYS =    0
STARTING HOUR OF SURFACE IRRIGATION =  0
ENDING HOUR OF SURFACE IRRIGATION =  0
NO SURFACE IRRIGATION INTERVAL 1 =   0      0
NO SURFACE IRRIGATION INTERVAL 2 =   0      0
MINIMUM AIR REQUIRED TO HAVE SURFACE IRRIGATION =    .00 CM
AMOUNT OF RAIN TO POSTPONE SURFACE IRRIGATION =    .00 CM
SURFACE IRRIGATION FOR ONE HOUR
   BY MONTH =     .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0 CM

****************************** END OF INPUTS ******************************
```

P00001915